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NASA CR-147465

SIGNATURE EXTENSION FOR SUN ANGLE

VOLUME II

J. A. Smith,
J. K. Berry,
and F. Heimes

Final Report
Earth Observations Division
NASA Johnson Spacecraft Center
NAS 9-14467

(E76-10273) SIGNATURE EXTENSION FOR SUN ANGLE, VOLUME 2 Final Report, 15 Nov. 1974 - 14 Nov. 1975 (Colorado State Univ.) 130 p HC $6.00 CSCL 03B
N76-21640
Unclas
G3/43 00273

November, 1975

Department of Earth Resources
Colorado State University
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THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL NASA POSITION, UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

ABSTRACT

This is the second volume in a two-volume final report series for Project NAS 9-14467 sponsored by the Earth Observations Division, NASA/JSC. This report series summarizes the work covered between the period November 15, 1974, and November 14, 1975. The objectives of the project were to evaluate the LACIE II table look-up approach to sun-angle correction. Canopy reflectance modeling was employed as a technique for evaluating sun-angle signature extension.

Volume I presents the multiplicative and additive coefficient matrices for a linear sun-angle correction approach. These coefficient tables are calculated using either measured empirical canopy reflectance functions or model derived data. These values are then incorporated into an atmospheric radiation transfer model. The dependence of the coefficient matrices on crop stage, crop type, and canopy directional reflectance variations is reviewed. Finally, a method for inferring leaf area index, an intrinsic scene characteristic, from canopy reflectance is discussed.

Volume II presents the basic data and computer programs used in the study. A brief review of the radiometric and geometric data collection procedures is also given. In particular, two recent methods developed by the investigators for determining plant geometry are discussed. These include the Fourier diffraction and multiple view angle approach. The data compilation consists of canopy reflectance, constituent reflectance, Leaf-Area-Indices, and leaf slope distributions for four wheat crop development stages at Garden City, Kansas.

FOREWORD

The research described in this report was supported under contract NAS9-14467, issued by the National Aeronautics and Space Administration, Earth Observations Division, Johnson Spacecraft Center, Houston, Texas. Mr. T. Barnett was the technical monitor of the project. The efforts described in this report represent Task 4.1.1.2 f(S) described in LACIE 00200, Volume III. Field data for the project were gathered over the LACIE Intensive Test Sites in Garden City, Kansas. The measurements were performed in cooperation with Dr. J. C. Harlan, Remote Sensing Center, Texas A & M University. Mr. Barrett Robinson, Laboratories for Applications of Remote Sensing, Purdue University, constructed the diffuse radiometer attachment for measuring leaf transmittance.

Participating project personnel included Dr. James A. Smith, Department of Earth Resources and Principal Investigator; Mr. Joe Berry, Graduate Research Assistant, and Mr. Rick Heimes, Graduate Research Assistant. Other project personnel included Miss Carol Conrad and Mrs. Pam Solomon, Colorado State University, who assisted in preparing the final report. Mr. Berry received the degree, Doctor of Philosophy, for work related to project sub-tasks.

The authors would particularly like to express their appreciation to Dr. Harlan and his research team for their field measurement support and to Dr. A. E. Potter, Chief of the Research, Test, and Evaluation Branch, Earth Observations Division, under whose auspices this work was performed.

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I. INTRODUCTION

This is the second volume in a two-volume report series for Project NAS9-14467 which represents Task 4.1.1.2f(s) in the LACIE 00200, Volume VIII. Specific objectives of this task in order of priority include:

A. To evaluate the current LACIE II table look-up sun angle correction algorithms relative to:
   1. The effect of canopy reflectance variations with sun angle;
   2. The effect of canopy sun angle reflectance variations with crop development stages;
   3. The effect of applying a uniform sun angle correction developed specifically for wheat to all crop types.

B. To recommend modifications to the current LACIE II sun angle correction algorithm.

C. To investigate the alternative sun angle correction procedures for present and future satellite systems. In particular, to investigate the possibility of extracting intrinsic scene characteristics from wheat canopy modeling.

The first volume in this report series summarizes the alpha, beta coefficient matrices required for a linear sun angle correction algorithm. The effects of crop stage, type, and canopy directional reflectance properties on the correction approach are reviewed. In addition, the relationship of Leaf-Area Index to canopy reflectance is discussed.

This volume provides a brief description of the field data collection techniques, Section II, and a complete listing of the radiometric and geometric data measured at the Garden City, Kansas, test sites for each of the four crop

development stages, Section III. Program listings and control cards for the computer programs used in the study are given in Section IV. The recently developed Fourier diffraction and multiple-view angle techniques for assessing plant geometry discussed in Section II should be of particular interest.

II. FIELD DATA COLLECTION TECHNIQUES

1.0 Radiometric Measurements

All of the reflectance data given in Volume II and analyzed in this report were collected with an Exotech ERTS radiometer which was modified for digital read out. The field procedure involved taking two readings centered on a row, then two more centered between rows for a total of four tripod movements. A white panel reference reading was made at each set-up. A final measurement of diffuse/direct irradiation was made by reading a sun-lit and shaded reference panel, respectively. These measurements were repeated for each of three intensive plots four times during the day. In addition, periodic bare soil reflectance measurements were made. Figures 1, 2, and 3 show the radiometer in its various field configurations.

Leaf transmission measurements were made using a special attachment for the ERTS radiometer that was developed by the Laboratory for Applications of Remote Sensing at Purdue University. The attachment consists of a cylindrical barrel, a sphere, and two flat discs which have small slots cut in them between which the leaf or other material is placed. The apparatus fits over the individual sensor ports on the ERTS radiometer and must be shifted to measure transmission for each of the four bands. Once the radiometer and attachment are aligned with the sun, it is a simple matter to shift from port to port for measurements in each band. The unit is aligned by the use of a pin-hole type site on the side of the barrel assembly. The barrel is directed towards the sun and collects the direct rays which pass into the sphere. The sphere is coated on the inside with $BaSO_4$ and contains a blocking baffle which prevents the passage of direct solar radiation through the sphere, allowing only diffuse radiation to pass. The diffuse light then passes through the material contained between the disc holders and is recorded by the sensor. The attachment is illustrated in Figures 4 and 5.

Figure 1. ERTS radiometer in its field configuration.

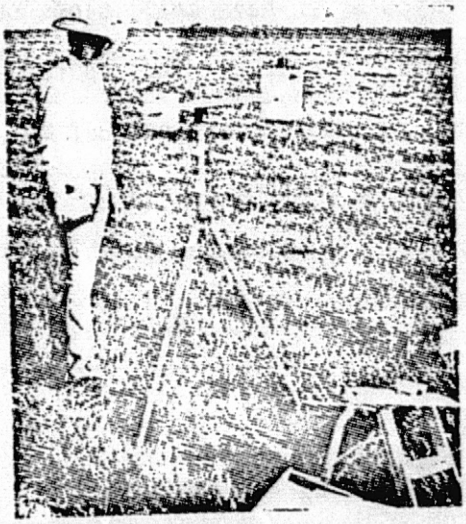


Figure 2. Four measurements were made (2 over a row and 2 between rows) for each "set-up" at an intensive site. Four such set-ups were completed during the day, covering a wide range of sun angles.

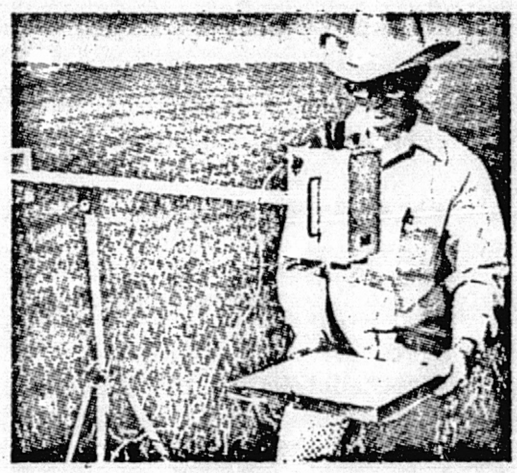


Figure 3. Percent reflectance for each band was determined by dividing the sample reading by a reading made from a white reflectance panel, which approximates total scene irradiance.

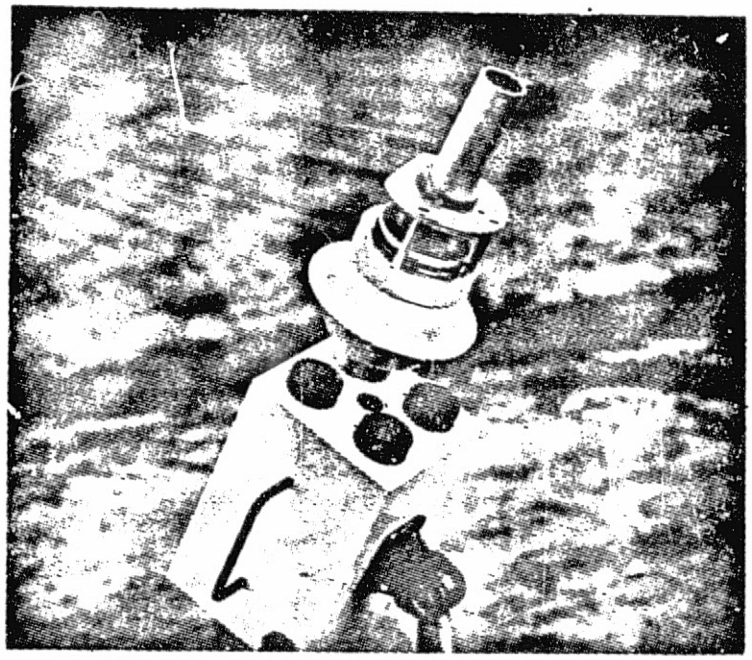


Figure 4. The leaf transmission attachment, in turn, is placed over each apeture. Two readings are made; the first is an unobstructed measure to establish a reference signal with the second having the leaf placed over the apeture of the attachment. The percent transmission of the leaf is calculated by dividing the reference signal by the sample reading.

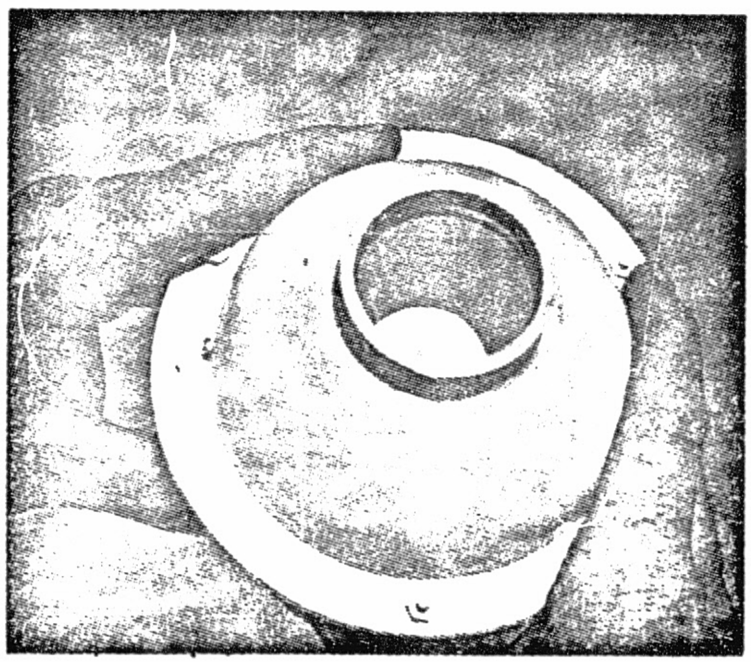


Figure 5. A baffle in the center of the sphere prevents direct sunlight from hitting the radiometer's detector and saturating the signal.

All radiometric data were recorded manually in the field as illustrated on the enclosed data sheet.

2.0 Techniques for Assessing Leaf Angle Distributions

A. Introduction

The Second Quarterly Progress Report referenced our preliminary work in developing rapid *in situ* techniques for measuring leaf slope distributions in wheat canopies. In particular, we discussed the Fourier diffraction and Fredholm approach. The field procedure for these two techniques has been implemented as part of the LACIE Field Measurements Program at Garden City, Kansas. Two alternative methods for measuring leaf slope distributions include the standard point quadrat approach and the orthogonal photographic method. The procedures for all four methods are described below.

B. Point Quadrat Technique

It has been shown that the mean foliage angle can be calculated from the number of contacts made by point quadrats passed vertically and horizontally through a plant canopy (Wilson, 1959). In practice the error associated with this method rarely exceeds 10% (Wilson, 1962). The technique is *in situ*, however appreciable localized trampling is induced around the field plot. The time required for a single angle determination is about 18 man hours (Knight, 1973). This method is most commonly used to characterize foliage geometry, however, it only estimates the mean inclination angle rather than a distribution.

The field procedure involves the calculation of the average number of contacts a long slender pin makes with the vegetation during a pass through the plant canopy. The length of the pass, for both the horizontal and vertical transects, is dictated by the height of the canopy. Several hundred passes are made from both directions, with the averages for each being multiplied by theoretically obtained coefficients to determine the mean foliage angle.

C. Orthogonal Tracing Technique

The distribution of foliage angles for an individual plant can be accurately determined by analyzing two orthogonal photos of the plant (Oliver and Smith, 1974). The distribution of angles for an entire plot is statistically determined by averaging the distributions of several representative plants. This technique has many of the limiting features associated with the point quadrat method. It is slow, tedious and destructive. However, its accuracy makes it a prime technique for evaluating the results of the other methods.

With this procedure, individual plants are clipped from a field plot and the silhouetted profiles are photographed from two orthogonal directions (Figure 1). The photographs (Figure 2) are then digitized by placing a transparent grid over the photographs and recording the two-dimensional coordinates of straight line segments along the profiles. The profiles are then plotted on microfilm (Figure 3) using the digitized data in order to verify the hand digitization. A computer program determines the three-dimensional coordinates of the foliage elements from the two sets of orthogonal data, and calculates the average foliage inclination angle by direct computation (Figure 4). The distribution for the entire plot is calculated by weighted averaging of the individual plant distributions based on the size of the plant.

D. Fredholm Integral Technique

This technique has the easiest data collection and reduction procedures of all the proposed methods. However, the technique cannot be applied to dense plant canopies (Oliver and Smith, 1974).

The proportion of gap or "probability of hit," as a function of view angle is a function of the mean canopy projection in the direction of view averaged over all foliage elements. Several explicit expressions of this

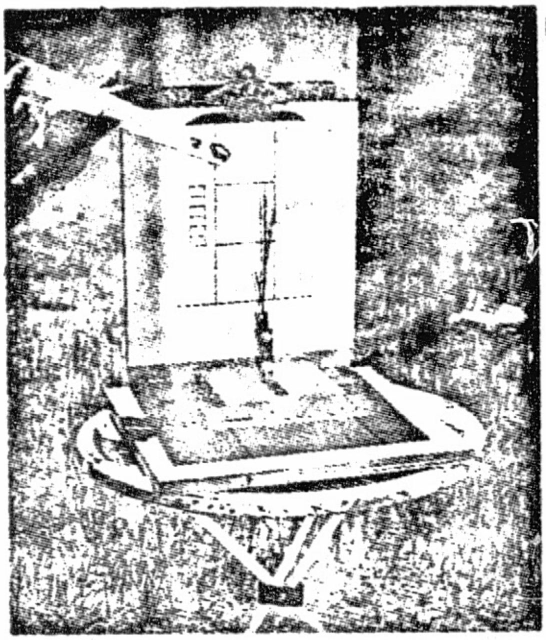


Figure 1. The field procedure for the orthogonal method involves making orthogonal photos of a silhouetted plant. Markers for several branches are used to avoid confusion when a pair of photos is digitized.

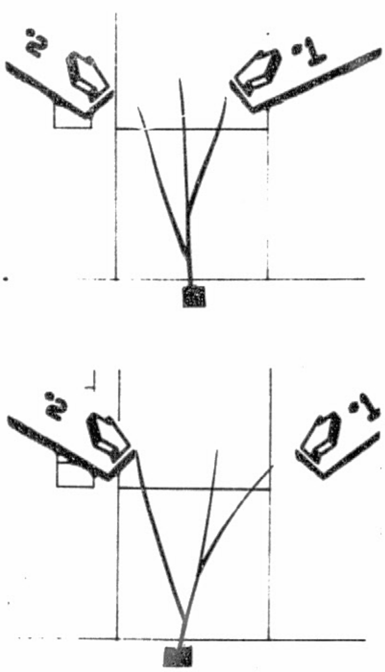


Figure 2. Orthogonal views of a silhouetted plant.

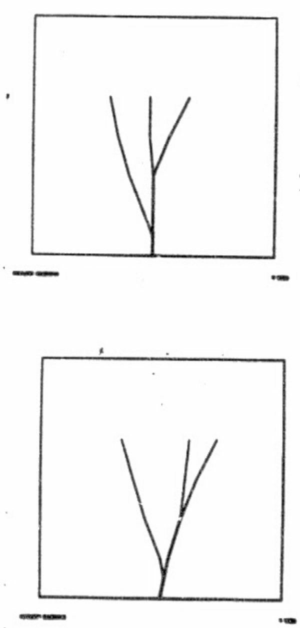


Figure 3. Computer plot of the digitized photos.

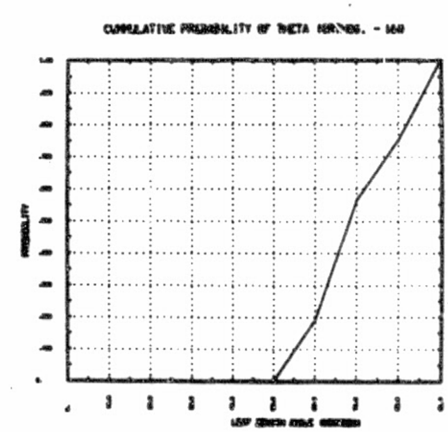


Figure 4. Distribution of angles of the plant in three-space. An estimate of angular bias within the canopy is made by averaging the distribution of several plants.

functional dependence are given in the literature (Nilson, 1971). For example: $P_o(\theta_r) = e^{-LAIg(\theta_r) \text{ Sec } \theta_r}$

where $g(\theta r)$ is the mean canopy projection in direction θ_r. LAI is leaf area index.

Given a measured $P_o(\theta r)$, we can then invert the expression to derive $g(\theta r)$.

This mean canopy projection in direction θr, $g(\theta r)$ can then be related to the leaf slope distribution $f(\theta a)$ via a Fredholm integral equation of the first kind (Oliver and Smith, 1974) $g(\theta r) = \int_0^{\pi/2} K(\theta,\theta a) f(\theta) d\theta$ where the kernel $k(\theta,\theta a)$ takes a different form depending on whether $\theta a \leq \frac{\pi}{a} - \theta r$ or $\theta a > \frac{\pi}{a} - \theta r$.

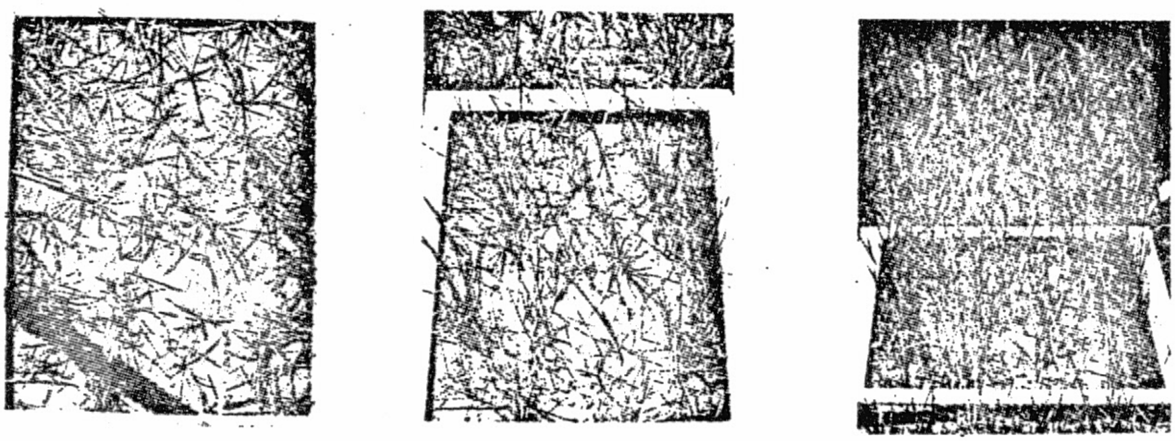
A numerical solution to this equation given a measured $P_o(\theta r)$ has been implemented in the CSU CDC 6400 computer, PROGRAM FREDHOLM. Program listings are given in Volume II.

The field proceudre for this technique involves taking a series of off-angle photos of a small plot (Figure 5 and 6). The probability of gap in each photo is determined by overlaying a transparent dot grid and recording the proportion of dots which do not intersect a foliage element. The vector of the probabilities of gap serves as input to a computer algorithm as discussed above which calculates the distribution of angles within the original plot (Figure 7).

E. Diffraction Pattern Technique

The diffraction pattern technique is much slower and more tedious than the Fredholm integral method, yet is still relatively easy and rapid when compared to either the point quadrat or orthogonal techniques. A limited localized distrubance of the canopy is encountered when field photographs are taken. Subsequent data reduction requires several photographic and measurement steps.

Figure 5. The field procedure for the Fredholm technique involves making a series of off-angle photos of the canopy.



0° Z 30° 60°

Figure 6. A full set of multiple view angle photos consists of all 10 increments between 0 and 70 Z. The probability of gap in each photo is determined by use of a transparent grid.

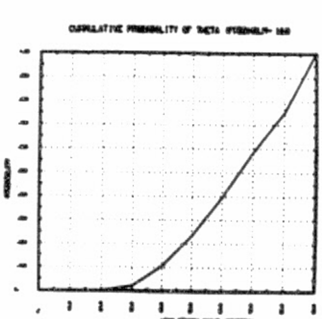


Figure 7. Distribution of angles for the entire canopy is calculated through the solution of a Fredholm integral equation.

This technique requires a horizontal field photo of a portion of the plant canopy silhouetted against a white backdrop (Figure 8). High contrast film is used to enhance the contrast between the plants and the backdrop. The negative of the field photo acts as input to an optical diffractometer (Figures 9 and 10) which generates a unique diffraction pattern dependent on the angles of the foliage elements. A high contrast photograph is taken of the diffraction pattern, and the negative measured using a photo cell densitometer (Figure 11). A wedge blocking filter is used on the densitometer in order to determine distribution of angles in the diffraction pattern. This distribution, in turn, serves as input to a computer algorithm, PROGRAM PROP, which solves for the distribution of angles in the original field scene (Figure 12). Program listings are given in Appendix B. A mathematical convolution of several scene angle distributions then yields the overall distribution of angles for the area.

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Knight, D. H. 1973. Leaf area dynamics of a shortgrass praire in Colorado. Ecology. Vol. 54, No. 4"891-896.

Nilson, T. 1971. A Theoretical Analysis of the Frequency of Gaps in Plant Canopies. Ag. Meteor. 8:25-38.

Wilson, J. W. 1959. Analysis of the spatial distribution of foliage by two-dimensional point quadrats. New Phytol., 58:92-100.

Wilson, J. W. 1962. Estimation of foliage denseness and foliage angle by inclined point quadrats. Aust. J. Bot., 11:95-105.

Oliver, R. E. and Smith, J. A. 1974. A stochastic canopy model of diurnal reflectance. Final report under contract DAHC04-74-G001, Colorado State University, Fort Collins, Colorado.

Figure 8. Field photos for the Fourier method are taken of silhouetted portions of the canopy.

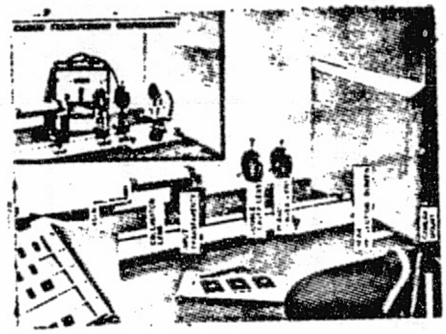


Figure 9. The high contrast field photos act as input to a LASER diffractometer which generates a unique diffraction pattern for each scene.

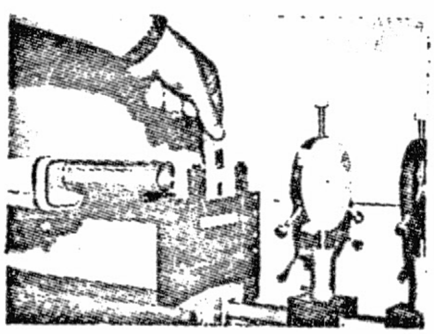


Figure 10. The input is placed between the LASER and a plano-convex lens. The quality of the diffraction pattern generated is primarily dependent on the alignment and cleanliness of the optics.

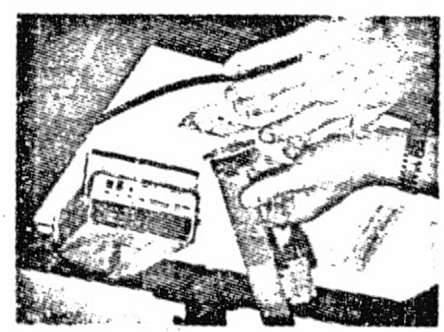
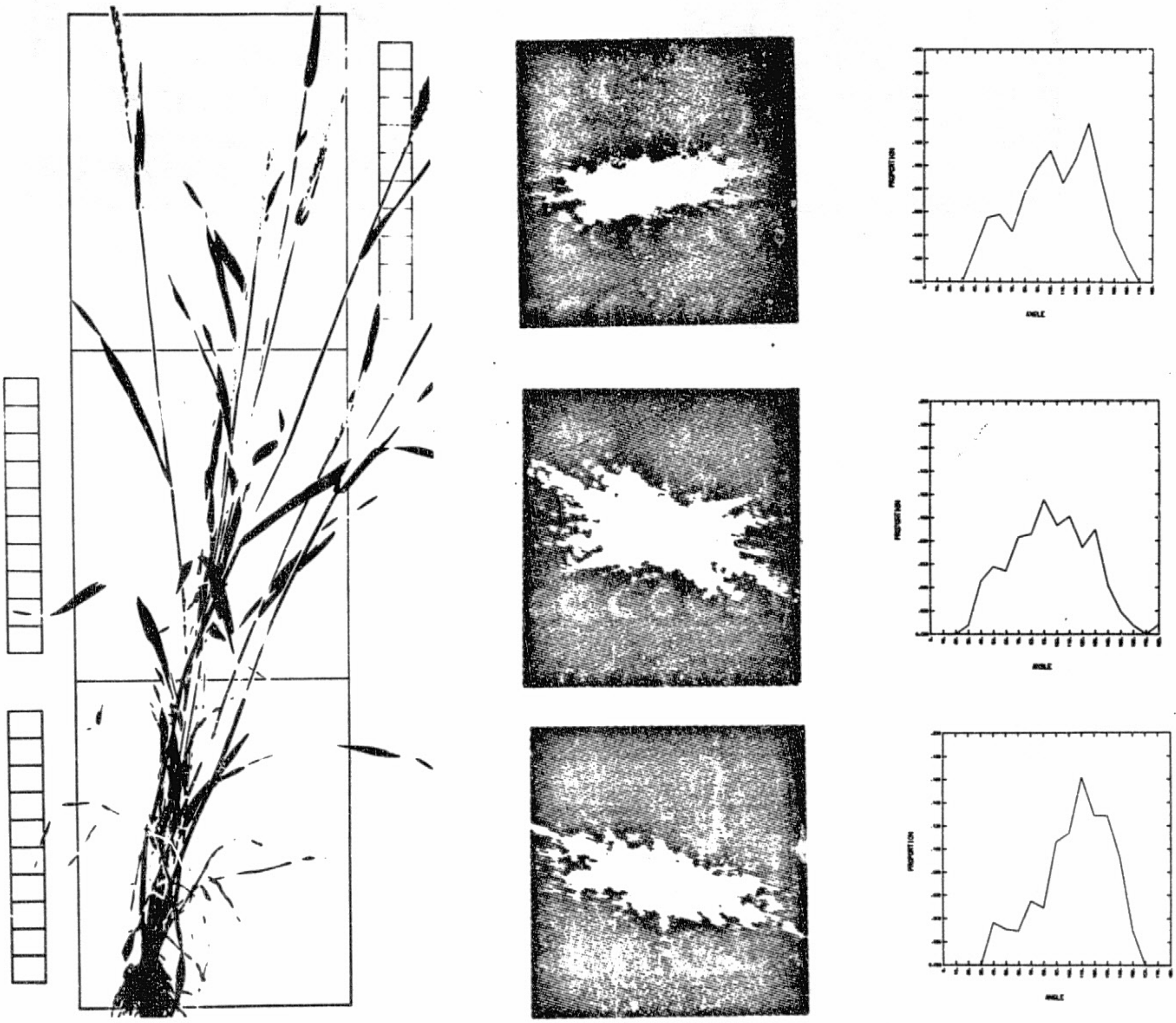


Figure 11. Sampling the angular information in the diffraction pattern is achieved by rotating a narrow wedge blocking filter attached to a photometer through half of the pattern. Program PROF reduces this information to a density function.



Input Scene Diffraction Pattern Distr. of Angles

Figure 12. An example of Fourier analysis for determining the leaf angle distribution of a wheat scene.

III. DATA COMPILATION

1. General Description

The principle field data collected by TAMU/CSU for the canopy modeling effort consists of periodic canopy reflectance, intensive leaf area index (LAI) measures, extensive LAI estimates, individual leaf transmission measurements, and canc geometry photos. Relatively complete data sets are available for March 20, 1975 (Tillering Stage, TAMU), April 23, 1975 (Jointing Stage, TAMU/CSU), and May 20, 1975 (Heading Stage, TAMU). Less complete data sets were collected on November 24, 1974 (Winter tillering stage, TAMU/CSU) and June 26, 1975 (Ripening stage, TAMU/CSU). The following two tables summarize the data sets. A more detailed presentation of each of these data sets is included in the remaining four parts of this section.

FINNEY COUNTY DATA SUMMARY
(Collected by TAMU/CSU)

I. March 20, 1975 — Tillering Stage — Field 416

- Canopy reflectance:

	Plot 1	Plot 2	Plot 3
Time:	1100 hrs.	1045	1030
	1145	1130	1115
	1300	1245	1230
	1400	1345	1330

- LAI:

Plot 1	Plot 2	Plot 3
2.07	4.06	1.31

- Canopy geometry: Fredholm field photos
- Leaf transmission: Not taken
- 10" LAI plots:

Field	367	369	370	414	421
Plot 1	1.82	.70	.50	1.46	.49
Plot 2	1.04	.41	1.60	.39	.35

II. April 23, 1975 Jointing Stage Field 416

- Canopy reflectance:

	Plot 1	Plot 2	Plot 3
Time:	1000 hrs.	1045	1115
	1130	1145	1200
	1315	1345	1400
	1715	1730	1800
- LAI:	5.13	5.36	6.15

- Canopy geometry: Fourier field photos
- Leaf transmission: Not taken
- 10" LAI plots:

Field	367	369	370	414	421
Plot 1	2.22	2.15	1.48	8.53	4.54
Plot 2	2.78	2.43	8.45	9.17	3.60

III. May 20, 1975 Heading Stage Field 416

- Canopy reflectance:

	Plot 1	Plot 2	Plot 3
Time:	0945 hrs.	1015	1045
	1100	1115	1130
	1200	1215	1245
	1300	1315	1345
- LAI:	4.11	5.32	6.04

- Canopy geometry: Fourier field photos
- Leaf transmission: Green, yellowing, dead
- 10" LAI plots:

Field	367	369	370	414	421
Plot 1	3.82	1.83	3.12	5.65	1.80
Plot 2	3.22	5.68	9.76	7.64	2.16

IV. June 26, 1975 Ripening Stage Field 416

- Canopy reflectance:

	Plot 1	Plot 2	Plot 3
Time:	--	1115	1000
	--	1200	1115
	--	1245	--
	--	1330	--
- LAI:	1.79	2.17	2.04

- Canopy geometry: Fourier field photos
- Leaf transmission: Dead
- 10" LAI plots:

Field	367	369	370	414	421
Plot 1	.78	1.15	.94	1.79	1.02
Plot 2	.85	2.00	3.14	2.63	1.08

In addition, the diffuse to direct irradiance ratio and soil reflectance were sampled periodically for each date.

LANDSAT RADIOMETER DATA
FOR FINNEY COUNTY FIELD SITE, KANSAS
(Averaged Over On-Off Row Set-Ups)

March 20	Band 4	5	6	7
PLOT 1				
1052 hrs.	.076	.078	.235	.315
1136	.065	.072	.217	.316
1304	.062	.059	.209	.299
1355	.067	.070	.210	.299
1635	.067	.075	.240	.329
PLOT 2				
1044	.075	.071	.260	.340
1127	.074	.070	.244	.333
1252	.066	.070	.237	.326
1342	.067	.069	.231	.322
1515	.074	.086	.242	.335
PLOT 3				
1033	.071	.083	.298	.475
1114	.055	.075	.300	.443
1236	.055	.050	.250	.383
1331	.060	.055	.258	.390
1623	.068	.073	.288	.430

April 23	Band 4	5	6	7
PLOT 1				
1009 hrs.	.023	.027	.249	.381
1128	.047	.033	.258	.409
1320	.058	.058	.258	.405
1738	.054	.029	.270	.416
PLOT 2				
1042	.039	.025	.266	.401
1146	.043	.030	.261	.381
1340	.049	.035	.275	.402
1738	.054	.025	.321	.503
PLOT 3				
1110	.040	.025	.262	.391
1203	.045	.031	.266	.395
1407	.049	.035	.276	.408
1754	.055	.025	.338	.519

May 20	Band 4	5	6	7
PLOT 1				
0945	.037	.028	.197	.320
1100	.038	.029	.201	.328
1200	.049	.038	.205	.293
1307	.048	.049	.206	.279
PLOT 2				
1018	.027	.023	.193	.290
1119	.029	.027	.161	.264
1220	.041	.033	.210	.307
1323	.043	.038	.193	.302
PLOT 3				
1042	.039	.026	.236	.333
1138	.038	.030	.217	.376
1245	.040	.036	.232	.392
1345	.047	.037	.251	.347

June 26	Band 4	5	6	7
PLOT 1				
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--
--	--	--	--	--
PLOT 2				
1110	.083	.098	.153	--
1154	.087	.116	.180	--
1240	.092	.124	.166	--
1325	.092	.117	.158	--
PLOT 3				
1006	.070	.134	.155	--
1119	.078	.113	.152	--
--	--	--	--	
--	--	--	--	--

2. Data Set Presentation

Reflectance Data and Associated Parameters

A. March 20, 1975 — Tillering Stage — Field 416

Crop type: Satanta Wheat (10" drill; EW)

Height: 8-9 cm.

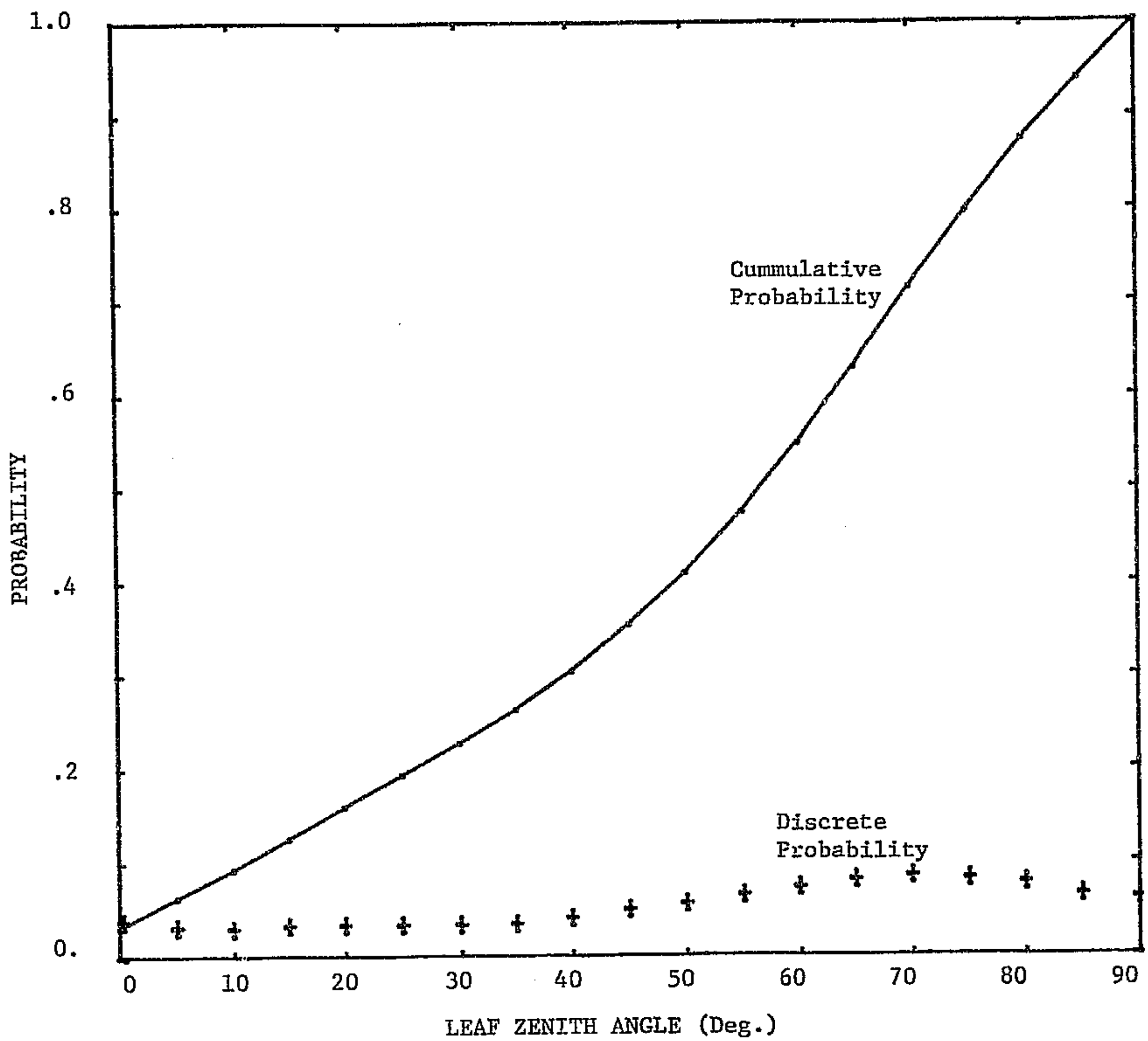
Chlorotic: Green foliage

Weeds: 0%

Soil condition: Moist

Wind: 12-15 mph NW

	PLOT 1	PLOT 2	PLOT 3
Leaf Area Index	2.07	4.60	1.31
Dry Weight (2' X 2' Plot)	58.10 gm	--	39.90
Number of Tillers (2' X 2' Plot)			
Live	803.00	--	1372.00
Dead	0.00	--	0.00
Total	803.00	--	1372.00
Average Tillers/Plant			
Live	8.64	--	11.00
Dead	0.00	--	0.00
Total	8.64	--	11.00
Average Leaf Area/Plant			
Green	37.39 cm^2	--	60.09
Yellow	0.00	--	0.00
Dead	0.00	--	0.00
Total	37.39	--	60.09



ANGLE(DEG)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
P(X)	.031	.032	.030	.033	.034	.034	.034	.035	.041	.050	.056	.065	.073	.081	.085	.082	.078	.065	.061

LEAF ANGLE DISTRIBUTION
FOR MARCH 20, 1975

DATE	TIME	CROP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE= BAND1	BAND2	BAND3	BAND4
032075	1052	WHEAT CSU	416-1	OFF ROW	.076	.091	.242	.338
032075	1055	WHEAT CSU	416-1	ON ROW	.078	.079	.254	.329
032075	1057	WHEAT CSU	416-1	ON ROW	.077	.078	.224	.293
032075	1058	WHEAT CSU	415-1	OFF ROW	.074	.074	.219	.319
032075	1059	WHEAT CSU	DIF	PERCENT	.085	.092	.050	.075
032075	1136	WHEAT CSU	416-1	OFF ROW	.063	.079	.217	.318
032075	1138	WHEAT CSU	416-1	ON ROW	.069	.075	.222	.337
032075	1140	WHEAT CSU	416-1	ON ROW	.053	.060	.222	.301
032075	1142	WHEAT CSU	415-1	OFF ROW	.066	.072	.208	.307
032075	1145	WHEAT CSU	DIF	PERCENT	.072	.062	.078	.102
032075	0104	WHEAT CSU	416-1	OFF ROW	.055	.060	.215	.296
032075	0105	WHEAT CSU	416-1	ON ROW	.060	.060	.190	.280
032075	0106	WHEAT CSU	415-1	ON ROW	.069	.050	.214	.314
032075	0107	WHEAT CSU	415-1	OFF ROW	.063	.065	.218	.306
032075	0133	WHEAT CSU	DIF	PERCENT	.088	.014	.095	.117
032075	0155	WHEAT CSU	416-1	ON ROW	.052	.070	.295	.294
032075	0156	WHEAT CSU	416-1	OFF ROW	.076	.075	.218	.307
032075	0158	WHEAT CSU	416-1	OFF ROW	.070	.074	.211	.291
032075	0159	WHEAT CSU	415-1	ON ROW	.070	.061	.265	.304
032075	0202	WHEAT CSU	DIF	PERCENT	.074	.004	.092	.118
032075	0210	WHEAT CSU	SOIL	REFLECT	.043	.078	.115	.142
032075	0435	WHEAT CSU	415-1	OFF ROW	.074	.075	.242	.311
032075	0436	WHEAT CSU	416-1	ON ROW	.061	.077	.210	.324
032075	0437	WHEAT CSU	416-1	ON ROW	.059	.073	.246	.343
032075	0441	WHEAT CSU	416-1	OFF ROW	.074	.075	.262	.347
032075	0444	WHEAT CSU	DIF	PERCENT	.130	.110	.109	.133
032075	1044	WHEAT CSU	416-2	ON ROW	.080	.066	.246	.333
032075	1045	WHEAT CSU	416-2	OFF ROW	.082	.066	.259	.359
032075	1046	WHEAT CSU	416-2	OFF ROW	.079	.077	.276	.358
032075	1047	WHEAT CSU	416-2	ON ROW	.078	.076	.259	.310
032075	1048	WHEAT CSU	DIF	PERCENT	.104	.075	.067	.074
032075	1127	WHEAT CSU	416-2	OFF ROW	.081	.069	.254	.338
032075	1127	WHEAT CSU	416-2	ON ROW	.068	.071	.239	.316
032075	1128	WHEAT CSU	416-2	ON ROW	.068	.069	.235	.338
032075	1129	WHEAT CSU	416-2	OFF ROW	.080	.070	.250	.339
032075	1132	WHEAT CSU	DIF	PERCENT	.069	.060	.059	.082
032075	1252	WHEAT CSU	416-2	OFF ROW	.065	.057	.244	.331
032075	1254	WHEAT CSU	416-2	ON ROW	.067	.075	.238	.333
032075	1256	WHEAT CSU	416-2	ON ROW	.069	.069	.225	.303
032075	1258	WHEAT CSU	416-2	OFF ROW	.065	.070	.241	.337
032075	1259	WHEAT CSU	DIF	PERCENT	.063	.014	.092	.112
032075	0142	WHEAT CSU	416-2	ON ROW	.063	.060	.232	.333
032075	0142	WHEAT CSU	416-2	OFF ROW	.068	.071	.239	.328
032075	0143	WHEAT CSU	416-2	ON ROW	.068	.074	.222	.314
032075	0144	WHEAT CSU	416-2	OFF ROW	.069	.071	.225	.311
032075	0145	WHEAT CSU	DIF	PERCENT	.061	.018	.079	.078
032075	0146	WHEAT CSU	SOIL	REFLECT	.066	.084	.112	.147
032075	0315	WHEAT CSU	416-2	ON ROW	.080	.092	.253	.360
032075	0335	WHEAT CSU	416-2	OFF ROW	.073	.082	.244	.333
032075	0339	WHEAT CSU	416-2	ON ROW	.071	.086	.229	.322
032075	0341	WHEAT CSU	416-2	OFF ROW	.071	.082	.241	.326
032075	0343	WHEAT CSU	DIF	PERCENT	.141	.160	.158	.189
032075	1033	WHEAT CSU	416-3	ON ROW	.070	.077	.300	.510
032075	1035	WHEAT CSU	416-3	ON ROW	.074	.080	.321	.470
032075	1036	WHEAT CSU	416-3	ON ROW	.070	.070	.270	.480
032075	1037	WHEAT CSU	416-3	OFF ROW	.070	.080	.300	.440
032075	1039	WHEAT CSU	DIF	PERCENT	.100	.030	.070	.080
032075	1114	WHEAT CSU	416-3	OFF ROW	.070	.070	.300	.430
032075	1115	WHEAT CSU	415-3	ON ROW	.070	.070	.300	.450
032075	1116	WHEAT CSU	416-3	ON ROW	.060	.090	.290	.460
032075	1117	WHEAT CSU	416-3	OFF ROW	.080	.080	.310	.430
032075	1118	WHEAT CSU	DIF	PERCENT	.090	.080	.100	.070

032075	1236	WHEAT CSU	416-3	ON ROW	.060	.050	.240	.380
032075	1237	WHEAT CSU	416-3	OFF ROW	.060	.050	.260	.380
032075	1238	WHEAT CSU	416-3	OFF ROW	.050	.050	.260	.380
032075	1239	WHEAT CSU	416-3	OFF ROW	.050	.050	.240	.390
032075	1240	WHEAT CSU	DIF	PERCENT	.080	.070	.100	.130
032075	0126	WHEAT CSU	416-3	OFF ROW	.060	.060	.270	.390
032075	0128	WHEAT CSU	416-3	ON ROW	.060	.050	.250	.400
032075	0130	WHEAT CSU	416-3	ON ROW	.050	.050	.250	.400
032075	0131	WHEAT CSU	416-3	OFF ROW	.060	.060	.260	.370
032075	0133	WHEAT CSU	DIF	PERCENT	.060	.020	.050	.100
032075	0135	WHEAT CSU	SOIL	REFLEC.	.070	.070	.120	.140
032075	0423	WHEAT CSU	416-3	OFF ROW	.073	.080	.300	.440
032075	0424	WHEAT CSU	416-3	ON ROW	.070	.070	.270	.420
032075	0425	WHEAT CSU	416-3	ON ROW	.070	.070	.290	.420
032075	0425	WHEAT CSU	416-3	OFF ROW	.080	.090	.290	.440
032075	0420	WHEAT CSU	DIF	PERCENT	.110	.110	.120	.130

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B. April 23, 1975 Jointing Stage Field 416

Crop type: Satanta Wheat (10" drill; EW)

Height: 28-35 cm

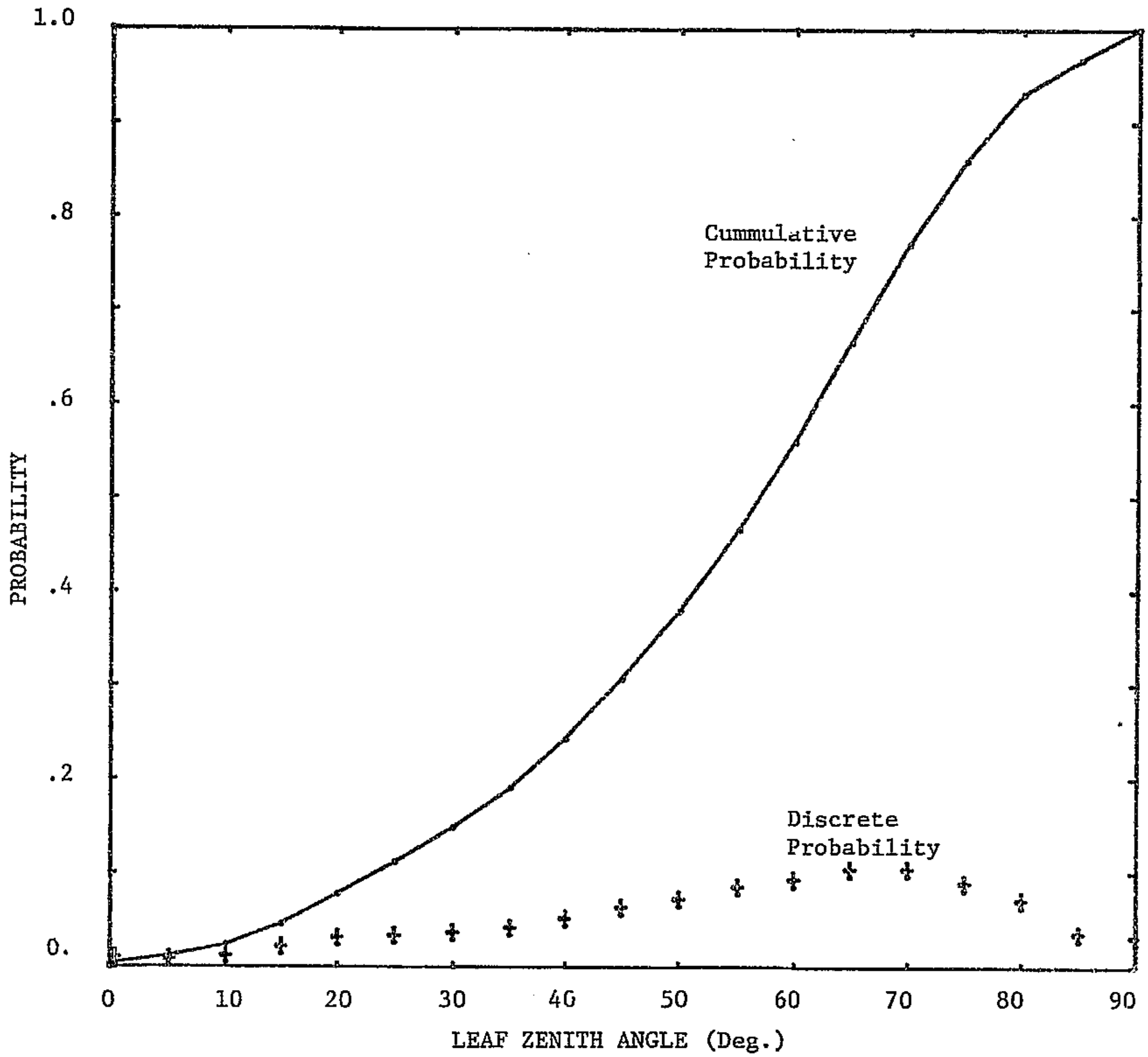
Chlorotic: 2-5% yellowing

Weeds: 0%

Soil condition: Dry

Wind: Calm

	PLOT 1	PLOT 2	PLOT 3
Leaf Area Index	5.13	5.36	6.15
Dry Weight (2' X 2' Plot)	142.24 gm	148.70	207.63
Number of Tillers (2' X 2' Plot)			
Live	907.00	1179.00	931.00
Dead	52.00	75.00	33.00
Total	959.00	1254.00	964.00
Average Tillers/Plant			
Live	8.80	10.80	8.40
Dead	.60	1.60	.80
Total	9.40	12.40	9.20
Average Leaf Area/Plant			
Green	100.84 cm^2	83.48	89.70
Yellow	33.21	42.50	19.16
Dead	40.99	32.02	31.49
Total	175.04	158.00	140.35



ANGLE(DEG) 0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
85 90

P(X) .003 .009 .012 .022 .032 .034 .037 .042 .052 .064 .073 .086
.094 .105 .105 .090 .072 .036 .032

LEAF ANGLE DISTRIBUTION
FOR APRIL 23, 1975

DATE	TIME	CROP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE= BAND1	BAND2	BAND3	BAND4
042375	1009	WHEAT CSU	416-1	ON ROW	.037	.023	.284	.407
042375	1013	WHEAT CSU	416-1	ON ROW	.036	.019	.251	.365
042375	1015	WHEAT CSU	416-1	OFF ROW	.050	.034	.252	.393
042375	1016	WHEAT CSU	416-1	OFF ROW	.041	.028	.262	.357
042375	1019	WHEAT CSU	DIF	PERCENT	.175	.147	.156	.145
042375	1128	WHEAT CSU	416-1	ON ROW	.043	.027	.280	.434
042375	1131	WHEAT CSU	416-1	ON ROW	.047	.031	.272	.437
042375	1133	WHEAT CSU	416-1	OFF ROW	.050	.035	.254	.394
042375	1135	WHEAT CSU	416-1	OFF ROW	.049	.038	.224	.369
042375	1136	WHEAT CSU	DIF	PERCENT	.143	.142	.144	.155
042375	0122	WHEAT CSU	416-1	OFF ROW	.071	.051	.240	.348
042375	0124	WHEAT CSU	416-1	OFF ROW	.055	.043	.222	.367
042375	0125	WHEAT CSU	416-1	ON ROW	.053	.036	.292	.462
042375	0127	WHEAT CSU	416-1	ON ROW	.052	.036	.277	.443
042375	0128	WHEAT CSU	DIF	PERCENT	.159	.130	.141	.143
042375	0521	WHEAT CSU	416-1	OFF ROW	.053	.024	.279	.395
042375	0523	WHEAT CSU	416-1	OFF ROW	.059	.028	.278	.404
042375	0525	WHEAT CSU	416-1	ON ROW	.051	.033	.253	.389
042375	0527	WHEAT CSU	416-1	OFF ROW	.052	.031	.270	.475
042375	0528	WHEAT CSU	DIF	PERCENT	.214	.195	.191	.203
042375	1042	WHEAT CSU	416-2	ON ROW	.039	.025	.284	.450
042375	1044	WHEAT CSU	416-2	ON ROW	.039	.025	.283	.434
042375	1046	WHEAT CSU	416-2	OFF ROW	.038	.023	.243	.350
042375	1048	WHEAT CSU	416-2	OFF ROW	.041	.026	.254	.371
042375	1049	WHEAT CSU	DIF	PERCENT	.179	.154	.154	.175
042375	1146	WHEAT CSU	416-2	ON ROW	.043	.031	.277	.413
042375	1148	WHEAT CSU	416-2	ON ROW	.042	.029	.298	.423
042375	1150	WHEAT CSU	416-2	OFF ROW	.041	.029	.221	.340
042375	1153	WHEAT CSU	416-2	OFF ROW	.044	.031	.247	.348
042375	1154	WHEAT CSU	DIF	PERCENT	.182	.150	.150	.171
042375	0140	WHEAT CSU	416-2	ON ROW	.047	.035	.300	.437
042375	0143	WHEAT CSU	416-2	ON ROW	.051	.037	.294	.441
042375	0146	WHEAT CSU	416-2	OFF ROW	.049	.035	.256	.356
042375	0148	WHEAT CSU	416-2	OFF ROW	.047	.032	.251	.372
042375	0150	WHEAT CSU	DIF	PERCENT	.145	.119	.135	.139
042375	0152	WHEAT CSU	SOIL	REFLECT	.150	.190	.261	.321
042375	0539	WHEAT CSU	416-2	ON ROW	.053	.025	.343	.577
042375	0540	WHEAT CSU	416-2	ON ROW	.057	.029	.352	.571
042375	0541	WHEAT CSU	416-2	OFF ROW	.048	.024	.294	.429
042375	0543	WHEAT CSU	416-2	OFF ROW	.056	.021	.293	.433
042375	0544	WHEAT CSU	DIF	PERCENT	.314	.195	.201	.203
042375	0547	WHEAT CSU	SOIL	REFLECT	.314	.195	.201	.203
042375	1110	WHEAT CSU	416-3	ON ROW	.047	.029	.305	.453
042375	1113	WHEAT CSU	416-3	ON ROW	.032	.019	.230	.347
042375	1114	WHEAT CSU	416-3	OFF ROW	.036	.023	.218	.344
042375	1115	WHEAT CSU	416-3	OFF ROW	.044	.028	.293	.421
042375	1119	WHEAT CSU	DIF	PERCENT	.183	.149	.152	.157
042375	1203	WHEAT CSU	416-3	ON ROW	.042	.027	.263	.401
042375	1207	WHEAT CSU	416-3	ON ROW	.050	.034	.291	.464
042375	1210	WHEAT CSU	416-3	OFF ROW	.045	.032	.280	.393
042375	1212	WHEAT CSU	416-3	OFF ROW	.041	.029	.230	.323
042375	1215	WHEAT CSU	DIF	PERCENT	.163	.131	.138	.154
042375	0207	WHEAT CSU	416-3	ON ROW	.050	.036	.301	.450
042375	0209	WHEAT CSU	416-3	ON ROW	.046	.034	.257	.415
042375	0211	WHEAT CSU	416-3	OFF ROW	.049	.037	.264	.366
042375	0212	WHEAT CSU	416-3	OFF ROW	.050	.034	.286	.402
042375	0213	WHEAT CSU	DIF	PERCENT	.129	.115	.130	.162
042375	1105	WHEAT CSU	SOIL	REFLECT	.119	.143	.255	.310
042375	0554	WHEAT CSU	416-3	ON ROW	.050	.026	.327	.521
042375	0555	WHEAT CSU	416-3	OFF ROW	.052	.027	.323	.502
042375	0557	WHEAT CSU	416-3	OFF ROW	.060	.023	.337	.478
042375	0559	WHEAT CSU	416-3	OFF ROW	.056	.023	.364	.508

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042375	0600	WHEAT CSU	DIF	PERCENT	.264	.241	.230	.234
042375	0602	WHEAT CSU	SOIL	REFLECT	.161	.207	.254	.362

C. May 20, 1975 Heading Stage Field 416

Crop type: Satanta Wheat (10" drill; EW)

Height: 72-89 cm

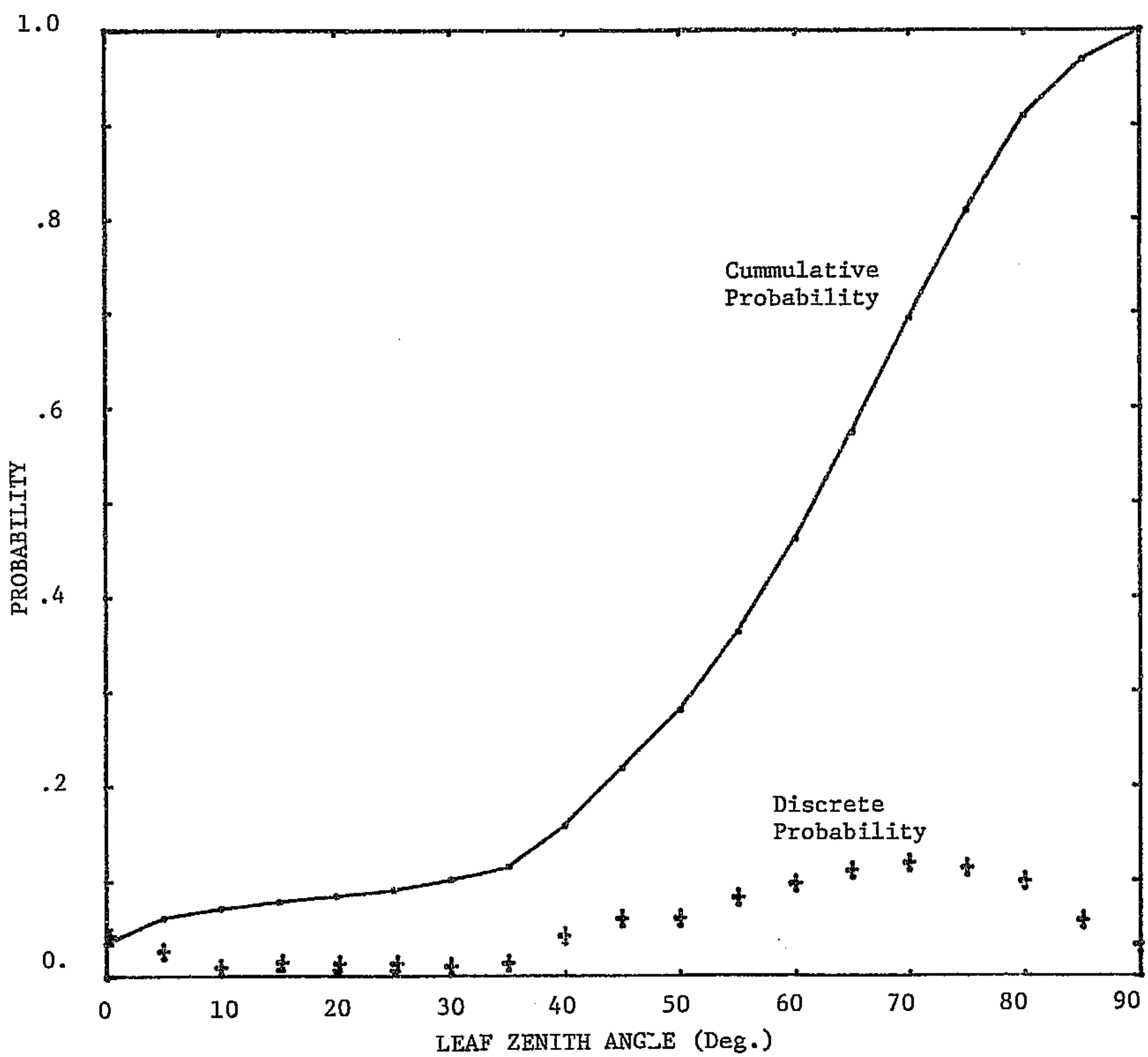
Chlorotic: 13% yellowing

Weeds: 0%

Soil condition: Dry

Wind: 10-15 mph EW

	PLOT 1	PLOT 2	PLOT 3
Leaf Area Index	4.11	5.32	6.03
Dry Weight (2' X 2' Plot)	197.70 gm	254.00	287.00
Number of Tillers (2' X 2' Plot)			
Live	--	--	--
Dead	--	--	--
Total	--	--	--
Average Tillers/Plant			
Live	4.80	5.60	4.60
Dead	3.40	1.40	2.60
Total	8.20	7.00	7.20
Average Leaf Area/Plant			
Green	95.26 cm^2	68.15	151.27
Yellow	12.88	5.09	18.25
Dead	68.13	28.97	74.94
Total	176.27	102.21	244.46



ANGLE(DEG)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
P(X)	.035	.027	.010	.007	.006	.006	.011	.014	.043	.061	.061	.083	.098	.112	.120	.115	.101	.059	.033

LEAF ANGLE DISTRIBUTION
FOR MAY 20, 1975

DATE	TIME	CROP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE= BAND1	BAND2	BAND3	BAND4
052075	0945	WHEAT CSU	416-1	OFF ROW	.044	.031	.200	.301
052075	0951	WHEAT CSU	416-1	ON ROW	.023	.017	.156	.200
052075	0955	WHEAT CSU	416-1	OFF ROW	.037	.029	.211	.331
052075	0959	WHEAT CSU	416-1	ON ROW	.043	.035	.222	.246
052075	1004	WHEAT CSU	DIF	PERCENT	.096	.083	.086	.105
052075	1100	WHEAT CSU	416-1	ON ROW	.033	.024	.152	.255
052075	1103	WHEAT CSU	416-1	ON ROW	.045	.039	.243	.404
052075	1105	WHEAT CSU	416-1	OFF ROW	.041	.030	.242	.359
052075	1109	WHEAT CSU	416-1	OFF ROW	.031	.024	.167	.265
052075	1111	WHEAT CSU	DIF	PERCENT	.088	.075	.097	.118
052075	1201	WHEAT CSU	416-1	OFF ROW	.050	.039	.200	.239
052075	1204	WHEAT CSU	416-1	OFF ROW	.053	.041	.243	.346
052075	1206	WHEAT CSU	416-1	ON ROW	.049	.037	.212	.314
052075	1208	WHEAT CSU	416-1	ON ROW	.043	.032	.163	.259
052075	1210	WHEAT CSU	DIF	PERCENT	.099	.094	.112	.122
052075	0107	WHEAT CSU	416-1	ON ROW	.044	.045	.182	.280
052075	0110	WHEAT CSU	415-1	OFF ROW	.050	.053	.177	.272
052075	0113	WHEAT CSU	416-1	OFF ROW	.051	.044	.224	.275
052075	0115	WHEAT CSU	415-1	ON ROW	.048	.052	.240	.290
052075	0119	WHEAT CSU	DIF	PERCENT	.063	.066	.088	.101
052075		WHEAT CSU	TRANS	GREEN1	.077	.058	.441	.594
052075		WHEAT CSU	TRANS	GREEN2	.079	.057	.416	.561
052075		WHEAT CSU	TRANS	YELLOW1	.177	.193	.457	.546
052075		WHEAT CSU	TRANS	YELLOW2	.269	.309	.434	.458
052075		WHEAT CSU	TRANS	YELLOW3	.212	.241	.420	.526
052075		WHEAT CSU	TRANS	YELLOW4	.111	.094	.397	.501
052075		WHEAT CSU	TRANS	DEAD	.059	.109	.215	.280
052075	1018	WHEAT CSU	415-2	OFF ROW	.024	.022	.198	.240
052075	1023	WHEAT CSU	415-2	ON ROW	.029	.026	.215	.352
052075	1025	WHEAT CSU	416-2	ON ROW	.032	.024	.171	.268
052075	1029	WHEAT CSU	415-2	OFF ROW	.023	.019	.187	.201
052075	1031	WHEAT CSU	DIF	PERCENT	.095	.074	.089	.108
052075	1114	WHEAT CSU	416-2	OFF ROW	.030	.024	.165	.247
052075	1121	WHEAT CSU	416-2	OFF ROW	.027	.025	.142	.268
052075	1123	WHEAT CSU	416-2	ON ROW	.027	.027	.178	.275
052075	1126	WHEAT CSU	416-2	ON ROW	.033	.030	.158	.264
052075	1130	WHEAT CSU	DIF	PERCENT	.077	.069	.080	.107
052075	1220	WHEAT CSU	415-2	OFF ROW	.043	.032	.234	.232
052075	1222	WHEAT CSU	416-2	OFF ROW	.042	.033	.209	.314
052075	1229	WHEAT CSU	416-2	ON ROW	.038	.034	.202	.271
052075	1232	WHEAT CSU	416-2	ON ROW	.041	.034	.195	.311
052075	1235	WHEAT CSU	DIF	PERCENT	.103	.087	.108	.132
052075	0123	WHEAT CSU	416-2	OFF ROW	.038	.036	.153	.274
052075	0126	WHEAT CSU	416-2	ON ROW	.040	.038	.198	.346
052075	0129	WHEAT CSU	416-2	OFF ROW	.052	.042	.223	.300
052075	0126	WHEAT CSU	416-2	ON ROW	.043	.037	.192	.286
052075	0136	WHEAT CSU	DIF	PERCENT	.101	.093	.097	.119
052075	0135	WHEAT CSU	SOIL	REFLECT	.190	.228	.210	.355
052075	1042	WHEAT CSU	416-3	OFF ROW	.039	.030	.252	.294
052075	1045	WHEAT CSU	415-3	ON ROW	.034	.024	.236	.284
052075	1047	WHEAT CSU	416-3	ON ROW	.041	.030	.236	.397
052075	1049	WHEAT CSU	416-3	OFF ROW	.042	.021	.221	.257
052075	1052	WHEAT CSU	DIF	PERCENT	.101	.090	.133	.150
052075	1138	WHEAT CSU	416-3	OFF ROW	.035	.023	.186	.338
052075	1142	WHEAT CSU	416-3	OFF ROW	.037	.029	.183	.313
052075	1144	WHEAT CSU	416-3	ON ROW	.035	.028	.227	.393
052075	1150	WHEAT CSU	415-3	ON ROW	.045	.039	.270	.461
052075	1152	WHEAT CSU	DIF	PERCENT	.085	.092	.112	.134
052075	1245	WHEAT CSU	416-3	OFF ROW	.047	.038	.209	.368
052075	1248	WHEAT CSU	416-3	OFF ROW	.039	.035	.239	.353
052075	1251	WHEAT CSU	416-3	ON ROW	.027	.032	.232	.421
052075	1254	WHEAT CSU	415-3	ON ROW	.046	.039	.247	.424

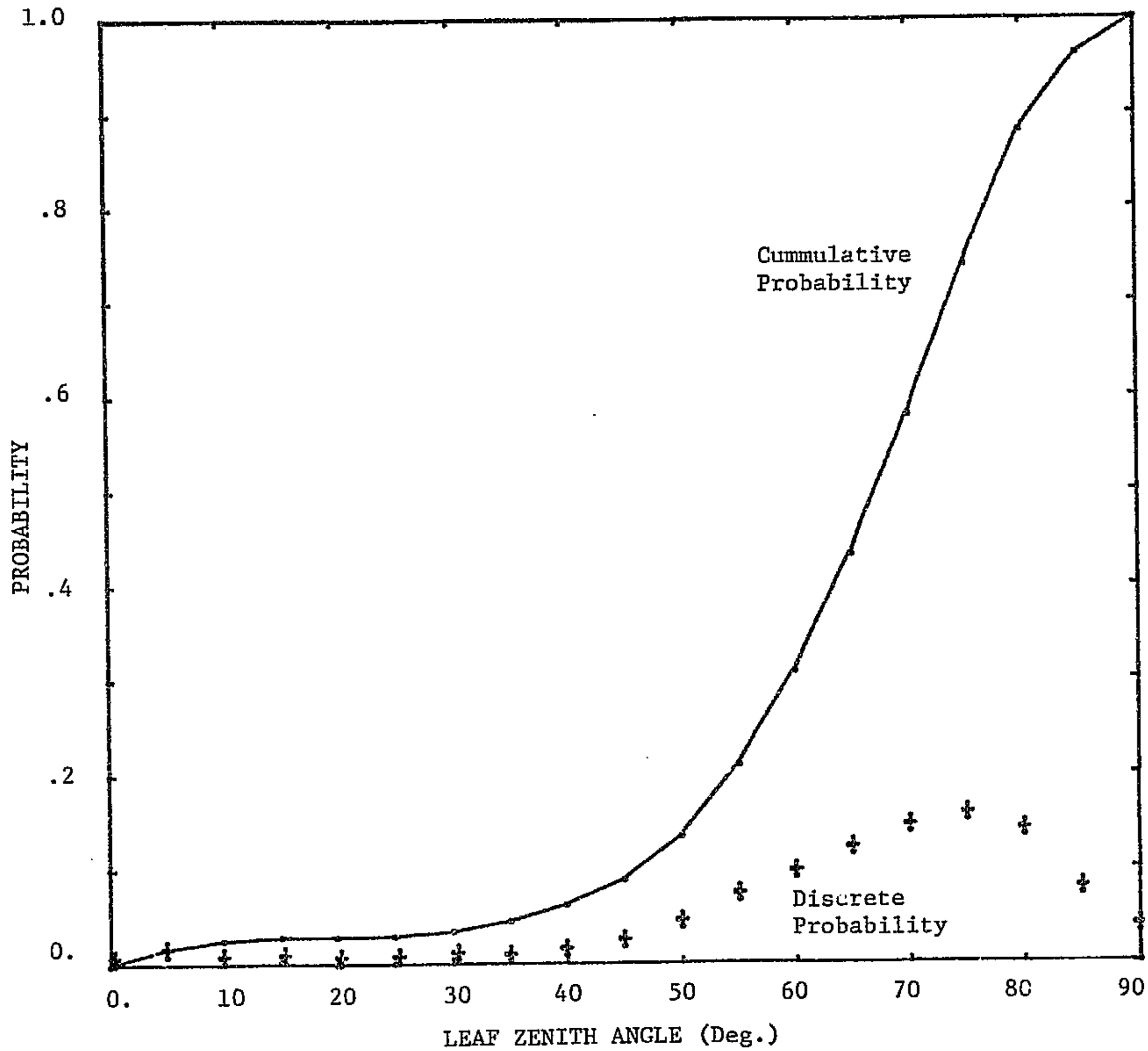
052075	1259	WHEAT CSU	DIF	PERCENT	.094	.083	.095	.111
052075	0145	WHEAT CSU	416-3	OFF ROW	.040	.034	.261	.389
052075	0146	WHEAT CSU	416-3	ON ROW	.045	.039	.250	.348
052075	0149	WHEAT CSU	416-3	ON ROW	.054	.037	.240	.339
052075	0151	WHEAT CSU	416-3	OFF ROW	.048	.039	.252	.313
052075	0153	WHEAT CSU	DIF	PERCENT	.070	.081	.096	.120
052075	0158	WHEAT CSU	SOIL	REFLECT	.129	.163	.239	.282
052075		WHEAT CSU	TRANS	GREEN1	.086	.058	.419	.566
052075		WHEAT CSU	TRANS	GREEN2	.076	.053	.395	.522
052075		WHEAT CSU	TRANS	YELLOW1	.185	.142	.484	.571
052075		WHEAT CSU	TRANS	YELLOW2	.325	.377	.507	.557
052075		WHEAT CSU	TRANS	YELLOW3	.194	.212	.451	.512
052075		WHEAT CSU	TRANS	YELLOW4	.303	.382	.504	.511
052075		WHEAT CSU	TRANS	DEAD	.083	.142	.226	.254

D. June 26, 1975 — Ripening Stage — Field 416

Crop type:	Satanta Wheat (10" drill; EW)
Height:	92-106 cm
Chlorotic·	All except stems and heads which are yellowing
Weeds:	0%
Soil condition:	Dry
Wind:	20-25 mph SN

	PLOT 1	PLOT 2	PLOT 3
Leaf Area Index	1.79	2.17	2.04
Dry Weight (2' X 2' Plot)	181.40 gm	219.70	206.70
Number of Tillers (2' X 2' Plot)			
Live	443.00	624.00	515.00
Dead	71.00	96.00	89.00
Total	514.00	720.00	604.00
Average Tillers/Plant			
Live	5.20	3.80	5.00
Dead	2.80	2.00	3.80
Total	8.00	5.80	8.80
Average Leaf Area/Plant			
Green	0.00	0.00	0.00
Yellow	76.38	54.80	78.23
Dead	70.72	42.59	66.46
Total	147.10	97.39	144.69

NOTE: The above measurements were conducted on June 18 and 19, 1975. However, due to adverse weather conditions at this time, collection of radiometric data was delayed until June 26, 1975. Radiometric data was collected by NASA, LEC personnel.



ANGLE(DEG)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
P(X)	0	.017	.009	.003	0	.001	.005	.011	.017	.026	.046	.075	.099	.124	.147	.159	.143	.081	.040

LEAF ANGLE DISTRIBUTION
FOR JUNE 26, 1975

DATE	TIME	CROP AND LOCATION	PLOT NUMBER	ORIENTATION	REFLECTANCE= BAND1	BAND2	BAND3	BAND4
061975	1050	WHEAT CSU	TRANS	DEAD1	.063	.172	.272	.300
061975	1100	WHEAT CSU	TRANS	DEAD2	.062	.172	.291	.345
062675	1110	WHEAT CSU	416-2	ON ROW	.112	.094	.163	0.000
062675	1112	WHEAT CSU	416-2	ON ROW	.102	.090	.179	0.000
062675	1114	WHEAT CSU	416-2	OFF ROW	.059	.100	.130	0.000
062675	1116	WHEAT CSU	416-2	OFF ROW	.059	.107	.140	0.000
062675	1115	WHEAT CSU	DIF	PERCENT	.108	.093	.097	*.000
062675	1154	WHEAT CSU	416-2	OFF ROW	.063	.102	.139	0.000
062675	1156	WHEAT CSU	416-2	OFF ROW	.061	.107	.133	0.000
062675	1158	WHEAT CSU	416-2	ON ROW	.109	.130	.221	0.000
062675	1200	WHEAT CSU	416-2	ON ROW	.114	.130	.225	0.000
062675	1159	WHEAT CSU	DIF	PERCENT	.052	.053	.059	*.000
062675	1240	WHEAT CSU	415-2	ON ROW	.110	.130	.205	0.000
062675	1242	WHEAT CSU	415-2	ON ROW	.110	.135	.202	0.000
062675	1244	WHEAT CSU	416-2	OFF ROW	.072	.113	.125	0.000
062675	1246	WHEAT CSU	416-2	OFF ROW	.074	.118	.125	0.000
062675	1245	WHEAT CSU	DIF	PERCENT	.085	.068	.079	*.000
062675	0125	WHEAT CSU	416-2	ON ROW	.101	.118	.180	0.000
062675	0127	WHEAT CSU	416-2	ON ROW	.101	.118	.176	0.000
062675	0129	WHEAT CSU	416-2	OFF ROW	.083	.112	.144	0.000
062675	0131	WHEAT CSU	416-2	OFF ROW	.081	.118	.132	0.000
062675	0130	WHEAT CSU	DIF	PERCENT	.066	.065	.075	*.000
062675	1006	WHEAT CSU	416-3	ON ROW	.079	.157	.198	0.000
062675	1008	WHEAT CSU	416-3	ON ROW	.081	.156	.199	0.000
062675	1010	WHEAT CSU	415-3	OFF ROW	.059	.112	.111	0.000
062675	1012	WHEAT CSU	415-3	OFF ROW	.059	.111	.111	0.000
062675	1010	WHEAT CSU	DIF	PERCENT	.138	.137	.151	*.000
062675	1119	WHEAT CSU	416-3	ON ROW	.103	.138	.204	0.000
062675	1121	WHEAT CSU	415-3	ON ROW	.103	.138	.201	0.000
062675	1123	WHEAT CSU	416-3	OFF ROW	.053	.088	.101	0.000
062675	1125	WHEAT CSU	415-3	OFF ROW	.054	.088	.101	0.000
062675	1124	WHEAT CSU	DIF	PERCENT	.099	.077	.102	*.000

IV. PROGRAM LISTINGS AND CONTROL CARDS

1. SRVC

Program Name: SRVC

Subroutines Required: BLOCK DATA
LAMBTN
SUN
ETHRES
LANGLE
NRM
SETZ
UTIL
COP
PDENS
PGAP
OPTICAL

Narrative:

The CSU SRVC (Solar Radiation Vegetation Canopy) (Oliver and Smith, 1974) is a stochastic model for simulating the interaction of global radiation with a vegetation canopy to determine its apparent directional reflectance. Input requirements for the model are:

1. Latitude of the target area
   Longitude of the target area
2. Time, date and solar declination
3. LAI (leaf area index)
4. Leaf slope distribution
5. Soil Reflectance
6. Diffuse/Direct Radiation Ratio
7. Leaf reflectance
   Leaf transmittance

Outputs from the model are:

1. Direction cosines of the sun
2. PHIT -- the probability of interaction of flux at specified source directions
3. Predicted apparent directional reflectance values for discrete wavelengths.

A thorough description of the model is given in the report by Oliver and Smith (1974). An abbreviated discussion of the model and its application is also given in the Applied Optics article by Smith and Oliver (1974).

A detailed flowchart of the SRVC main program is included and program listings are well-commented.

Control Card Input:

Card 1	(8A10)	Title
Card 2		
	(I3)	Day
	(I4)	Year
	(I2)	Hours
	(I2)	Minutes
	(F6.2)	Latitude)
	(F7.2)	Longitude)
	(F7.2)	Declination
	(I2)	Bandwidth
Card 3		
	(I2)	Number of wavelengths
	(I1)	Number of constituents
	(I5)	Initialization variable
	(I5)	Number of samples desired
	(I5)	Number of trials desired
Card 4		
	(I10)	Number of canopy layers
Card 5		
	(8F10.5)	Threshold vector for downward flux
Card 6		
	(8F10.5)	Threshold vector for upward flux
Card 7		
	(I10)	Number of angles in leaf slope
Card 8		
	(I10)	Material type
Card 9		
	(8F10.5)	Leaf angle distribution
Card 10		
	(2F10.5)	S factor; leaf area index

Cards 7-10 - repeat for each canopy layer

Card 11

	(8F10.5)	Wavelengths

Card 12

	(I10,7A10)	Number of input optimal vectors Description

Card 13

	(8F10.5)	Optical vector

Cards 11-13 - repeat for:
measured canopy reflectance
total study irradiance
total diffuse irradiance
soil reflectance
leaf reflectance
leaf transmittance

Mathematical Model

The Monte Carlo model assumes that the canopy is composed of nonhomogeneous layers of Lambertian surfaces of known optical properties, statistical composition, and geometric arrangement. The model is presented schematically in Figure 1.

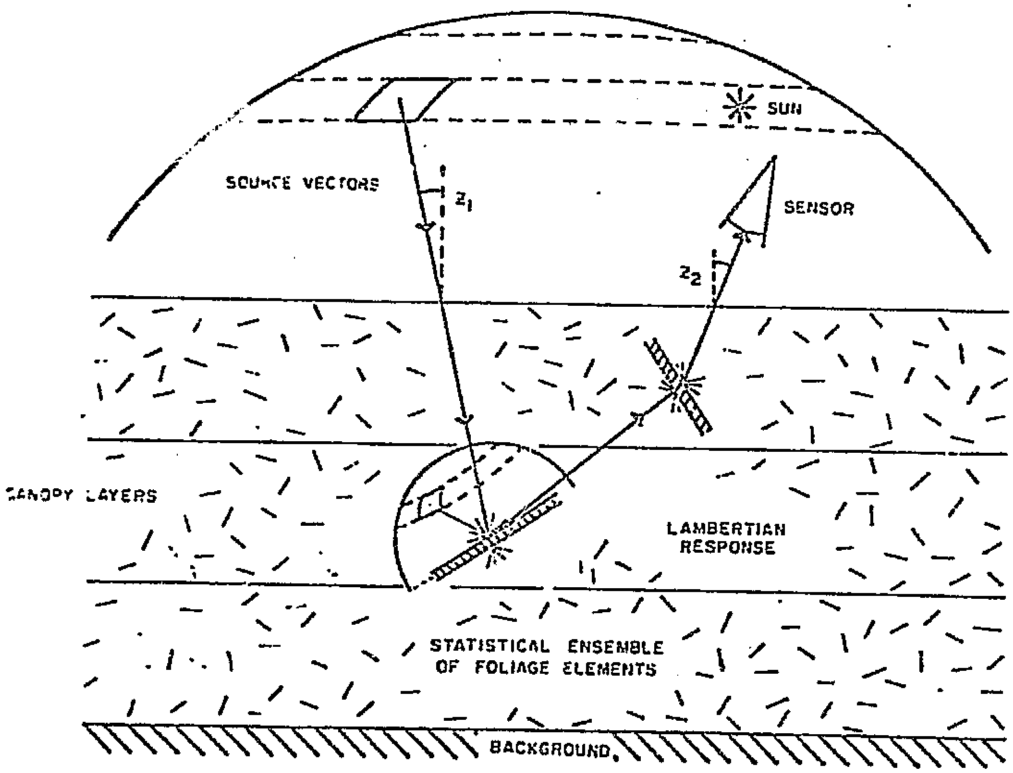


Figure 1. Schematic of a Plant Canopy Approximated by Stratified Foliage Layers Containing Statistical Ensembles of Lambertian Surfaces.

Global radiation which reaches the top of the vegetation canopy is composed of direct solar and diffuse sky radiation. The partitioning into fractions of total radiation is determined from the position of the sun, i.e., time of day, latitude, and solar declination, and from measured global and diffuse sky radiation distributions incident on a horizontal sensor. The direct solar radiation component is treated as a point source whereas the diffuse fraction is divided into source sectors of the local hemisphere. These sectors are formed by partitioning the hemisphere into 10 degree inclination bands and further subdividing these bands to form 20 degree azimuthal sectors. The interaction with the canopy of each of these initial radiation sources is treated independently.

Diffuse flux resulting from the interaction of global radiation with a canopy element or with the background become new sources which may further interact with the canopy. The downward directed flux is combined with the appropriate hemispherical band of diffuse sky radiation. Upward directed flux is treated in a similar manner as diffuse sky radiation except the direction associated with each sector is the opposite from incoming radiation from that sector.

A frequency distribution of foliage inclination angle is determined for each layer from the geometric measurements of the canopy and is integrated using Simpson's rule to obtain a cumulative frequency distribution. This integral is normalized and partitioned into areas of equal

probability. The domains of each partition have equal probability of occurrence and may be sampled from a uniform distribution.

The next step in the model is to calculate the interaction probabilities within each layer for both incoming and outgoing flux at each specified source direction. Several potential expressions are available in the literature cited (Idso and deWit, 1970; Pielou, 1969; and Nilson, 1971). The following expressions from Idso and deWit have been employed:

$$P_o = \left[1 - s\, g(\theta_r) \sec \theta_r\right]^{LAI/s}$$

where P_o is the probability of a gap

$g(\theta_r)$ is the mean canopy projection in the direction of the source

θ_r is the source zenith angle

LAI is the leaf area index for the canopy

s is the leaf area index of statistically independent incremental canopy layers.

it is usually adjusted by optimizing the reflection prediction for either one view angle or a set of wavelengths since it does not change with either wavelength or view angle.

A given source finds a gap in the top layer of the canopy if a random number is smaller than P_o. The flux in this direction passes through the top layer and reaches the next canopy layer. The absence of a gap necessitates the determination of material type with which contact has been made. This is accomplished by sampling from the distribution of canopy constituents. The orientation of the leaf is

determined by sampling from the inclination distribution and a uniform azimuthal distribution. These parameters determine the direction cosines of the leaf from which the angle between the leaf and the source is determined. The optical properties of the leaf are then utilized to calculate the flux exiting the leaf in all directions. Each sector of the hemisphere on the reflecting side of the leaf receives flux for each wavelength according to the equation:

$$I = \frac{I_o}{18} \rho \sin(\theta_{LS}) \left(\sin^2\theta_2 - \sin^2\theta_1\right)$$

where I_o is the source spectral flux

ρ is the material spectral reflectance

θ_{LS} is the angle between the leaf and the source

θ_1, θ_2 are the inclination angles defining the hemispherical band

The solid angle sectors receiving reflected and transmitted flux are defined in the same manner as for canopy flux sources only extended to include the entire sphere about the leaf. The leaf is not necessarily horizontal so a sector receiving reflected flux from the leaf is not necessarily directed upward with respect to the local vertical. Hence, the direction cosines of the flux sector are rotated to the local vertical system and the flux pooled with the flux in the appropriate source band. Transmitted flux is calculated and treated in the same manner as reflected flux.

Flux which passes through a gap or is reflected or transmitted downward from an upper layer of the canopy interacts with the next lower layer. Flux which reaches the soil surface is reflected into each of the upward directed source bands. Upward directed flux from a lower layer of the canopy or from the background reaches the next higher layer and may interact with it. The upward directed flux from the top layer escapes the canopy.

The interaction procedure continues until the level of flux in any source direction within any layer is below a threshold value. The flux exiting the canopy into each of the bands is separately accumulated. The ratio of the flux intercepted by a sensor placed within one of these bands to the global radiation intercepted by a vertical sensor with the same field of view gives the canopy apparent directional reflectance.

Figure 2 shows the calculated mean response surface in the visible wavelength region for zenith view angles of 5 to 65 degrees. The non-Lambertian character of the canopy reflectance is evident and there is a general increase in canopy reflectance with increasing zenith angle. This variation of reflectance with view angle is significant for the pattern recognition process. Sensor scan angle corrections may be required or this variation might be utilized as an additional characteristic feature. The distortion in the response surface with view angle indicates that methods employing channel ratio techniques for preprocessing (Kriegler, 1971) or for specialized classification

approaches (Pearson and Miller, 1972) may require modification in some circumstances.

The model was evaluated (Smith and Oliver, 1972; Oliver and Smith, 1973) for a Blue grama canopy with a leaf area index of 6.5. Figure 3 shows a comparison of the model results, labeled SRVC 2-layer, with measured data for a vertical view angle. Agreement is good except for the chlorophyll absorption band. Recent evidence (Breece and Holmes, 1971) indicates that the foliage surfaces are non-Lambertian in this region which will necessitate a modification to the model assumptions for regions of strong absorption. Off-angle predictions of the model are qualitatively correct but do not display the same precision as the vertical view case (Smith and Oliver, 1972). Prediction results using the original Kubelka-Munk model of Allen and Richardson (1968) are also shown for comparison.

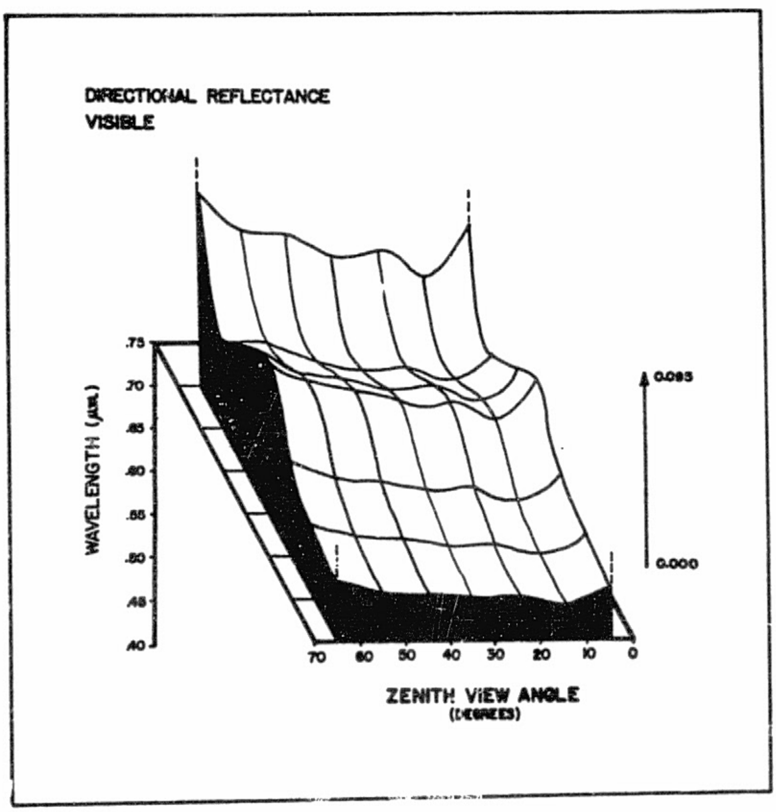


Fig. 2 Calculated mean response surface for reflectance changes with zenith view angle and wavelength.

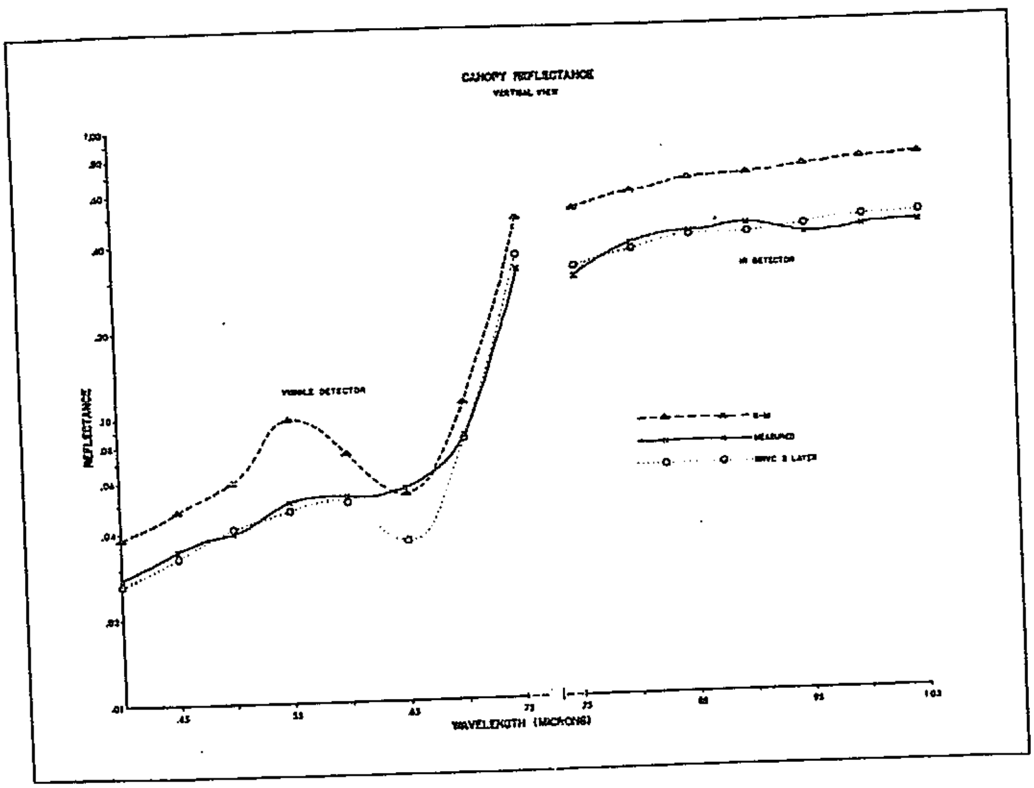


Fig. 3 Comparison of calculated Kubelka-Munk differential equation model and the stochastic SRVC model predictions with measured canopy reflectance for a vertical view angle.

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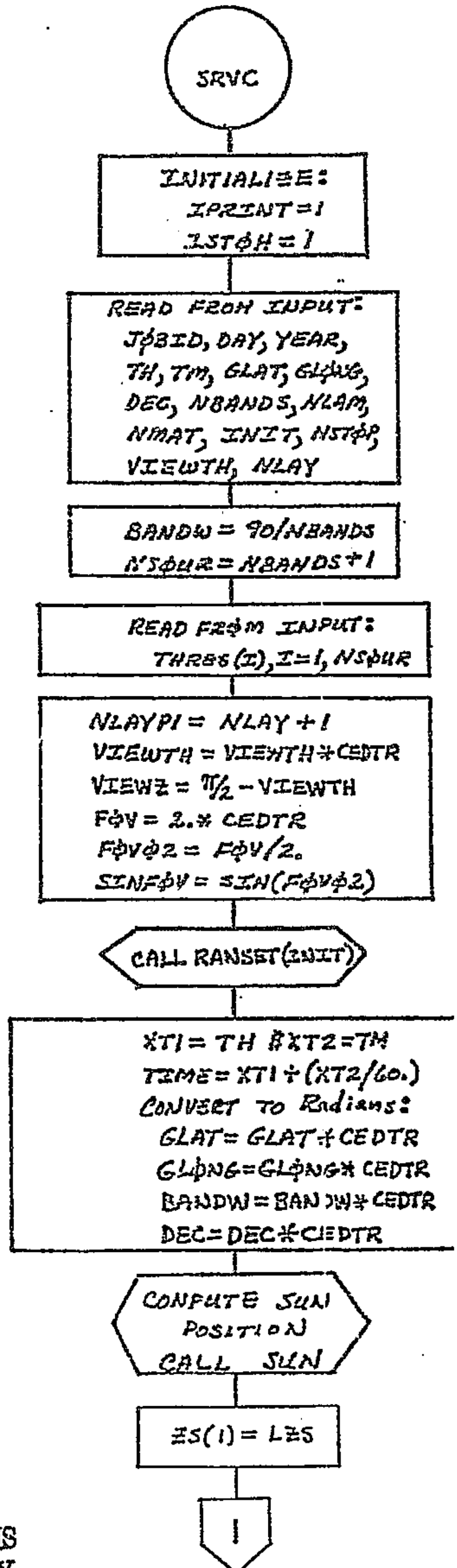
PROGRAM FLOWCHART
FOR SRVC



1

$XK(I) = \sin^2(I*10^\circ) - \sin^2((I-1)*10^\circ)$

$I = 1, NBANDS$

Relative contribution to the illuminance of the horizontal surface of 10 degree zones from a sky with uniform brightness.

Source inclination angles

$THETA(1) = \pi/2 - ACOS(COS(Z))$

$(2) = 5^\circ$

$(3) = 15^\circ$

$\vdots$

$(10) = 85^\circ$

$$CONS = \frac{\sum_{I=1}^{NBANDS=9} XK(I) * \sin[THETA(I+1)]}{\cos(Z)}$$

$DMI(I) = \dfrac{\sin^2(FOV/2.)}{XK(I-1)}$

$I = 2, NSOUR$

Ratio of sensed flux to total flux entering the band (escaping)

FIND ISENS AND ISUN,
THE INDICES OF THE DIFFUSE
BANDS CONTAINING THE SENSOR
AND THE SUN.

DIRECTION COSINES OF AZIMUTHAL
SECTORS IN THE DIFFUSE BANDS.

XS(JSOR, IPHI) = COS(THETA(JSOR)) * COS(PHI)

YS(JSOR, IPHI) = COS(THETA(JSOR)) * SIN(PHI)

ZS(JSOR) = SIN(THETA(JSOR))

where JSOR = 2, NSOUR AND IPHI
varies FROM 1,2,...,18 (PHI=10°; 0°,...,350°)
FOR EACH JSOR.

2

IL = 0

IL = IL + 1

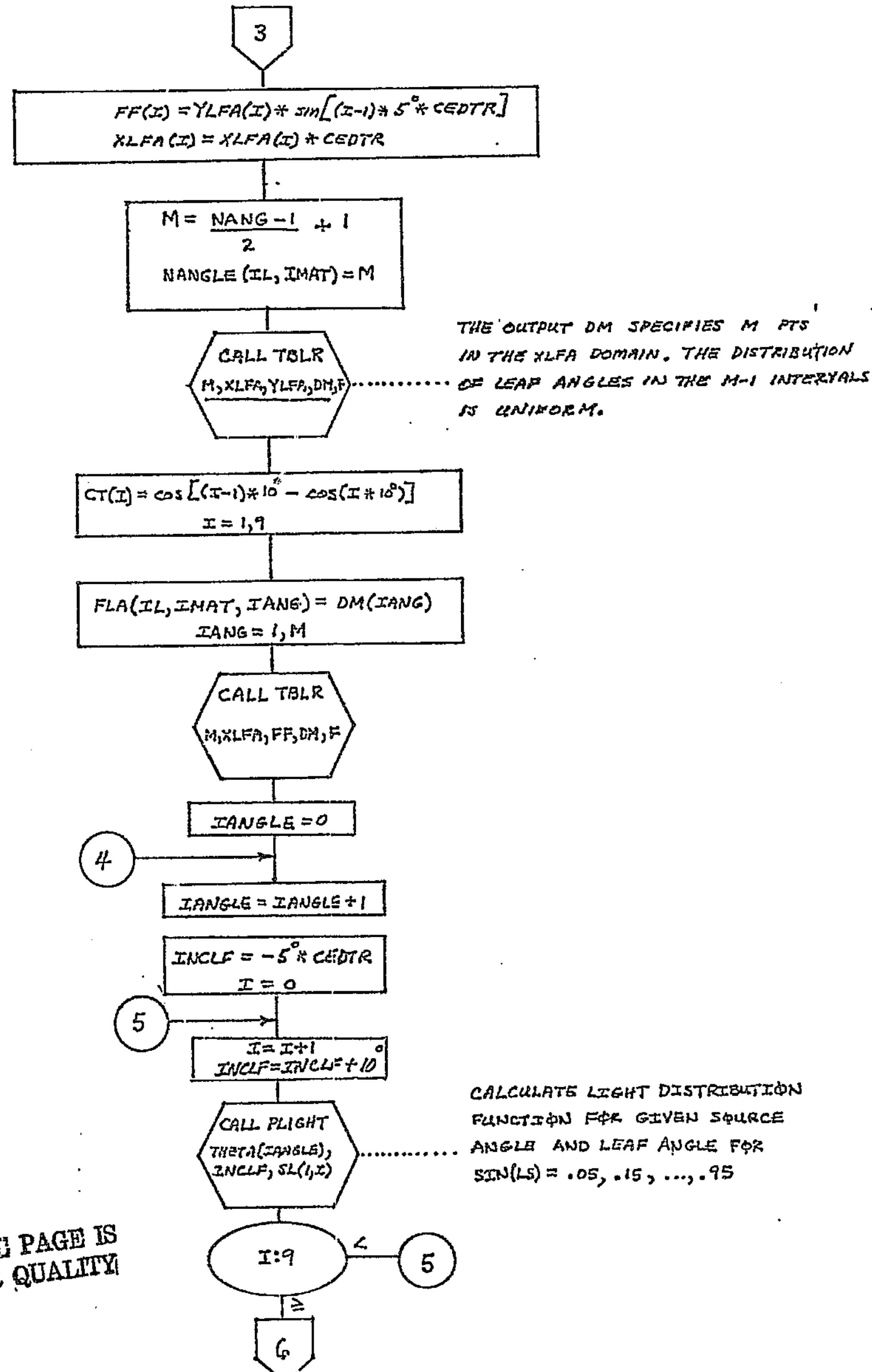
READ FROM INPUT:
NANG, IMAT

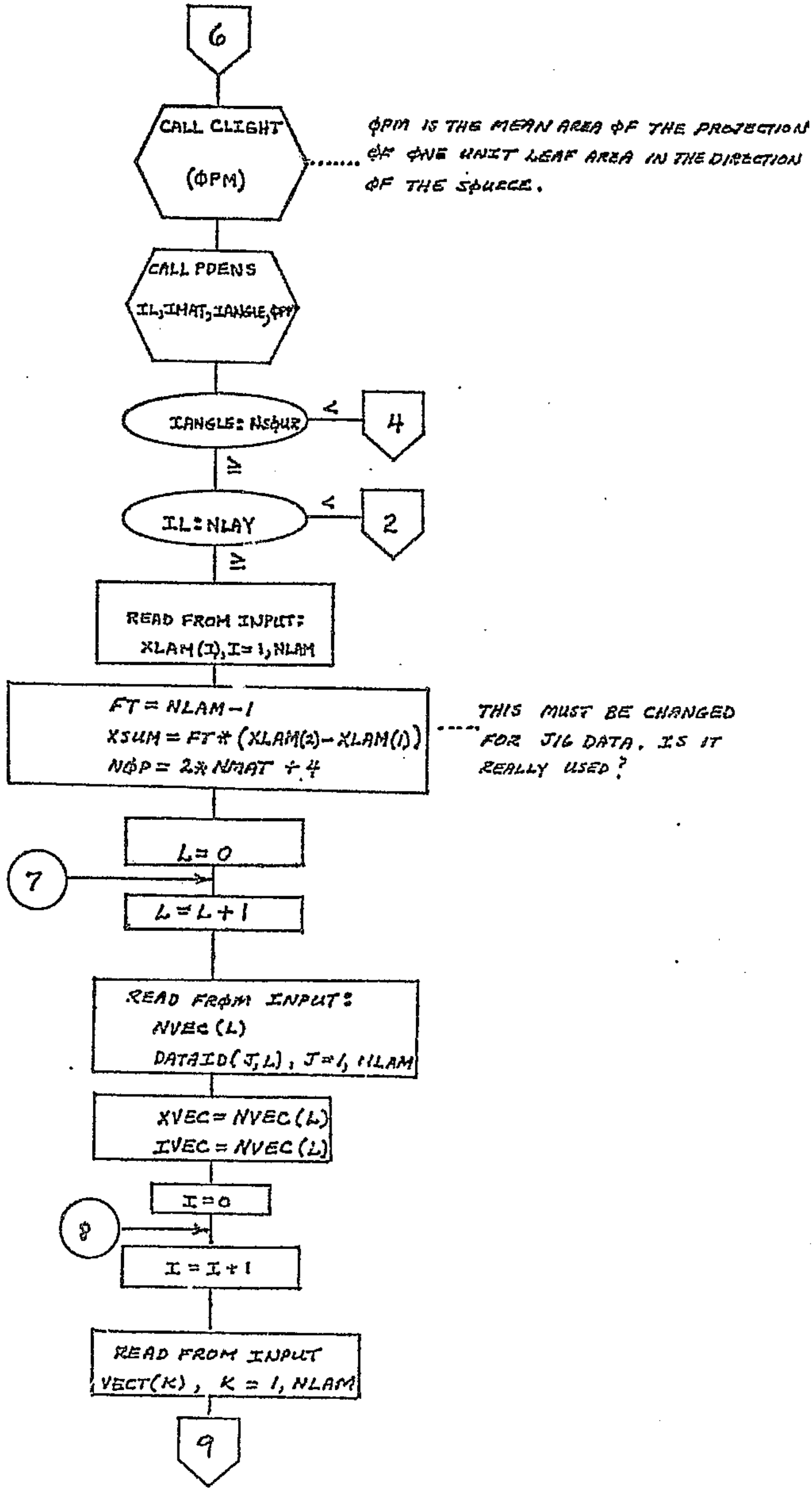
MTP(IL) = IMAT

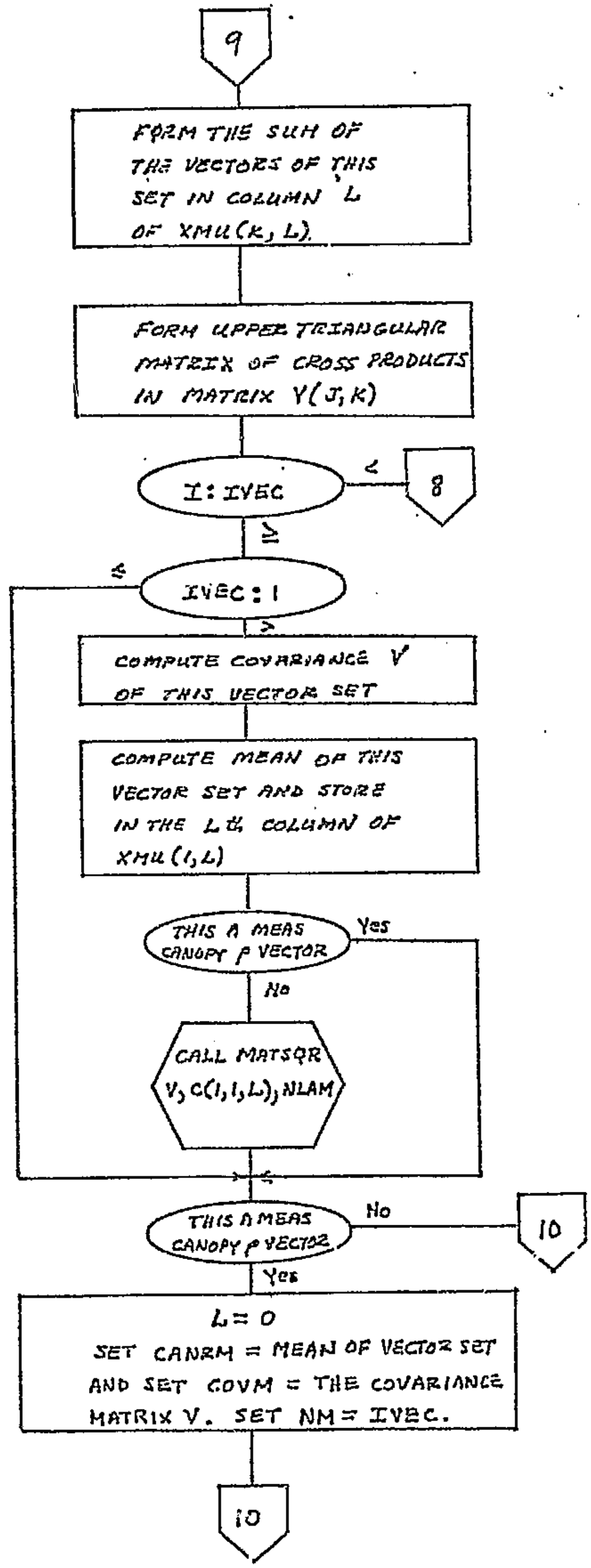
Material type in layer IL

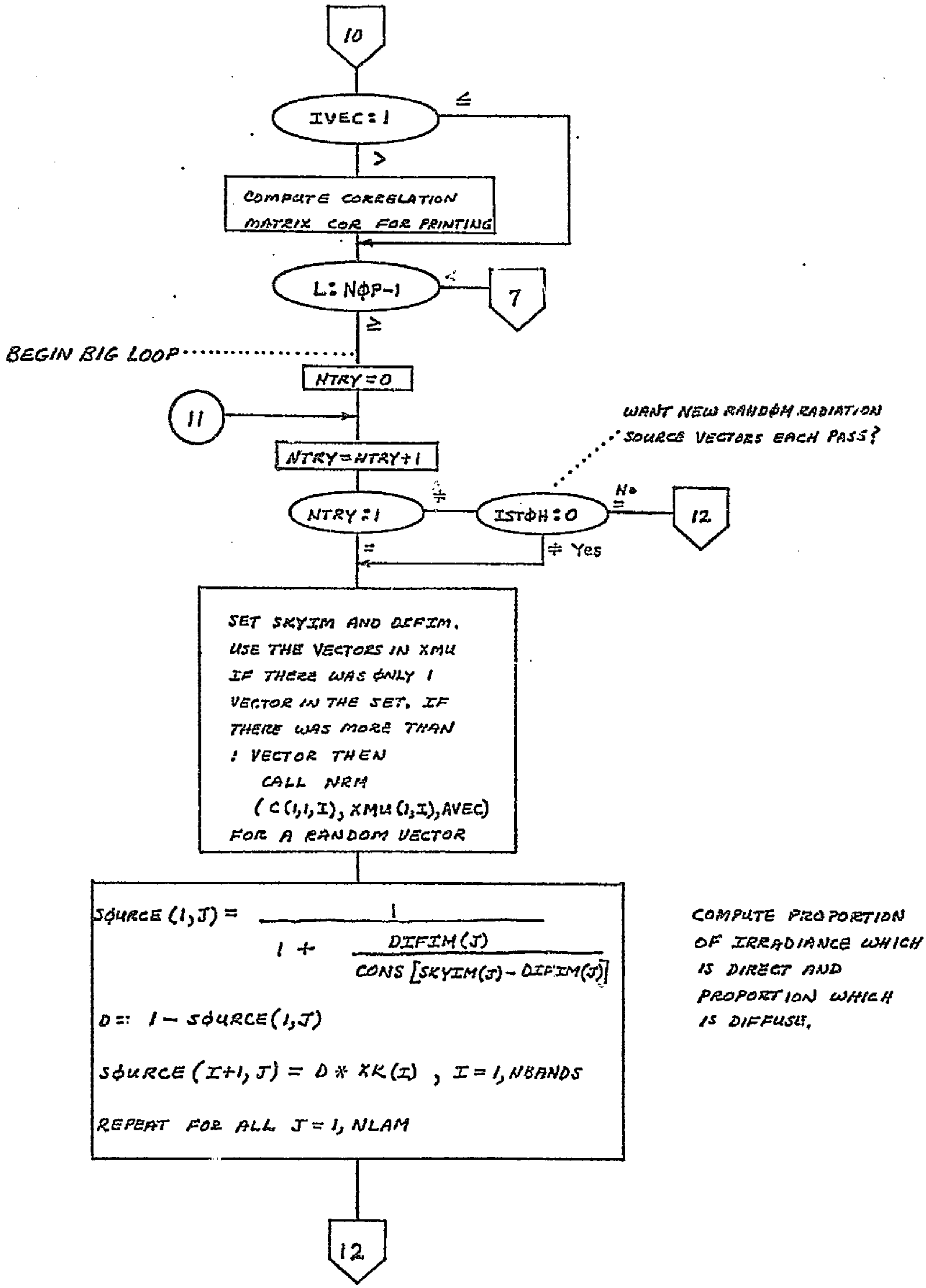
READ FROM INPUT:
XLFA(I), YLFA(I), I = 1, NANG
SLAI(IL,IMAT), FLAI(IL,IMAT)

3

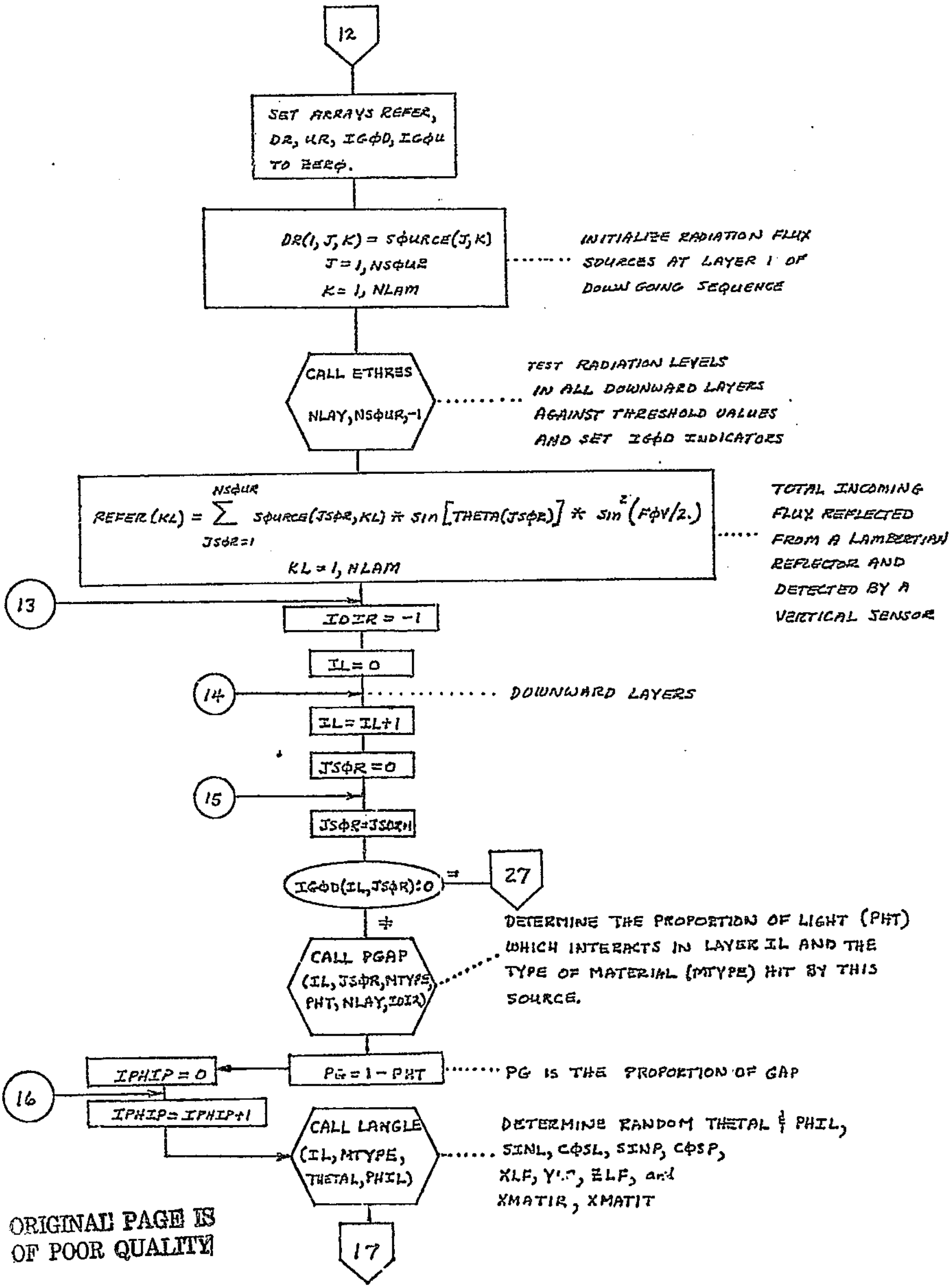

3
FF(I) = YLFA(I) * sin[(I-1) * 5° * CEDTR]
XLFA(I) = XLFA(I) * CEDTR
M = (NANG - 1)/2 + 1
NANGLE (IL, IMAT) = M
CALL TBLR
M, XLFA, YLFA, DM, F
THE OUTPUT DM SPECIFIES M PTS IN THE XLFA DOMAIN. THE DISTRIBUTION OF LEAF ANGLES IN THE M-1 INTERVALS IS UNIFORM.
CT(I) = cos[(I-1) * 10° - cos(I * 10°)]
I = 1,9
FLA(IL, IMAT, IANG) = DM(IANG)
IANG = 1, M
CALL TBLR
M, XLFA, FF, DM, F
IANGLE = 0
4
IANGLE = IANGLE + 1
INCLF = -5° * CEDTR
I = 0
5
I = I+1
INCLF = INCLF + 10°
CALL PLIGHT
THETA(IANGLE), INCLF, SL(1,I)
CALCULATE LIGHT DISTRIBUTION FUNCTION FOR GIVEN SOURCE ANGLE AND LEAF ANGLE FOR SIN(LS) = .05, .15, ..., .95
I:9
<
5
≥
6

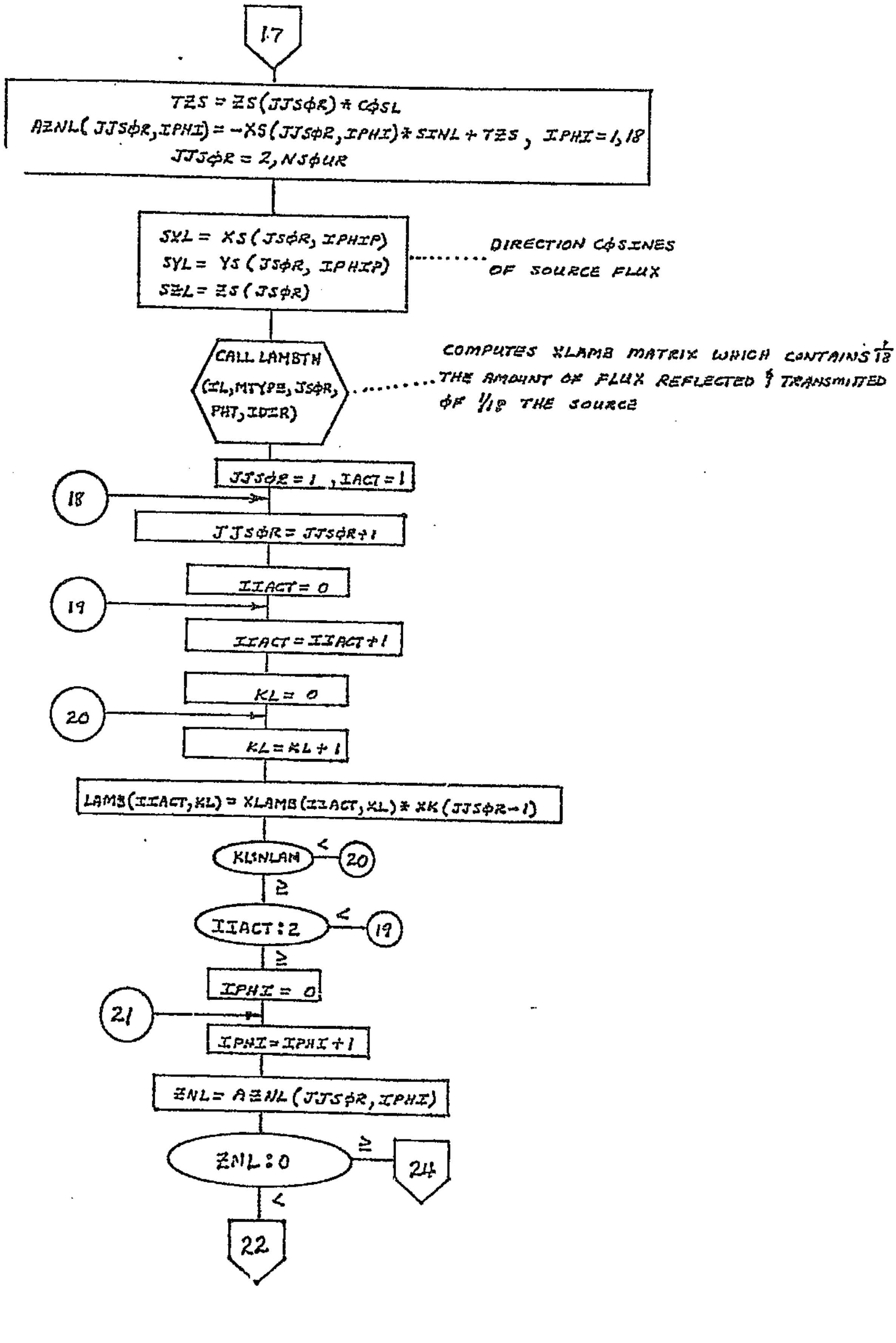

6
CALL CLIGHT
(ΦPM)
ΦPM IS THE MEAN AREA ΦF THE PROJECTION ΦF ΦNE UNIT LEAF AREA IN THE DIRECTION ΦF THE SΦURCE.
CALL PDENS
IL, IMAT, IANGLE, ΦPM
IANGLE : NSΦUR
<
4
≥
IL : NLAY
<
2
≥
READ FROM INPUT:
XLAM(I), I = 1, NLAM
FT = NLAM − 1
XSUM = FT * (XLAM(2) − XLAM(1))
NΦP = 2 * NMAT + 4
THIS MUST BE CHANGED FOR JIG DATA. IS IT REALLY USED?
L = 0
7
L = L + 1
READ FRΦM INPUT:
NVEC (L)
DATAID (J, L), J = 1, NLAM
XVEC = NVEC (L)
IVEC = NVEC (L)
I = 0
8
I = I + 1
READ FROM INPUT
VECT(K), K = 1, NLAM
9


9
FORM THE SUM OF THE VECTORS OF THIS SET IN COLUMN L OF XMU(K, L).
FORM UPPER TRIANGULAR MATRIX OF CROSS PRODUCTS IN MATRIX Y(J, K)
I : IVEC
<
8
≥
IVEC : 1
≤
>
COMPUTE COVARIANCE V OF THIS VECTOR SET
COMPUTE MEAN OF THIS VECTOR SET AND STORE IN THE Lth COLUMN OF XMU(I, L)
THIS A MEAS CANOPY ρ VECTOR
Yes
No
CALL MATSQR V, C(1, 1, L), NLAM
THIS A MEAS CANOPY ρ VECTOR
No
10
Yes
L = 0
SET CANRM = MEAN OF VECTOR SET AND SET COVM = THE COVARIANCE MATRIX V. SET NM = IVEC.
10

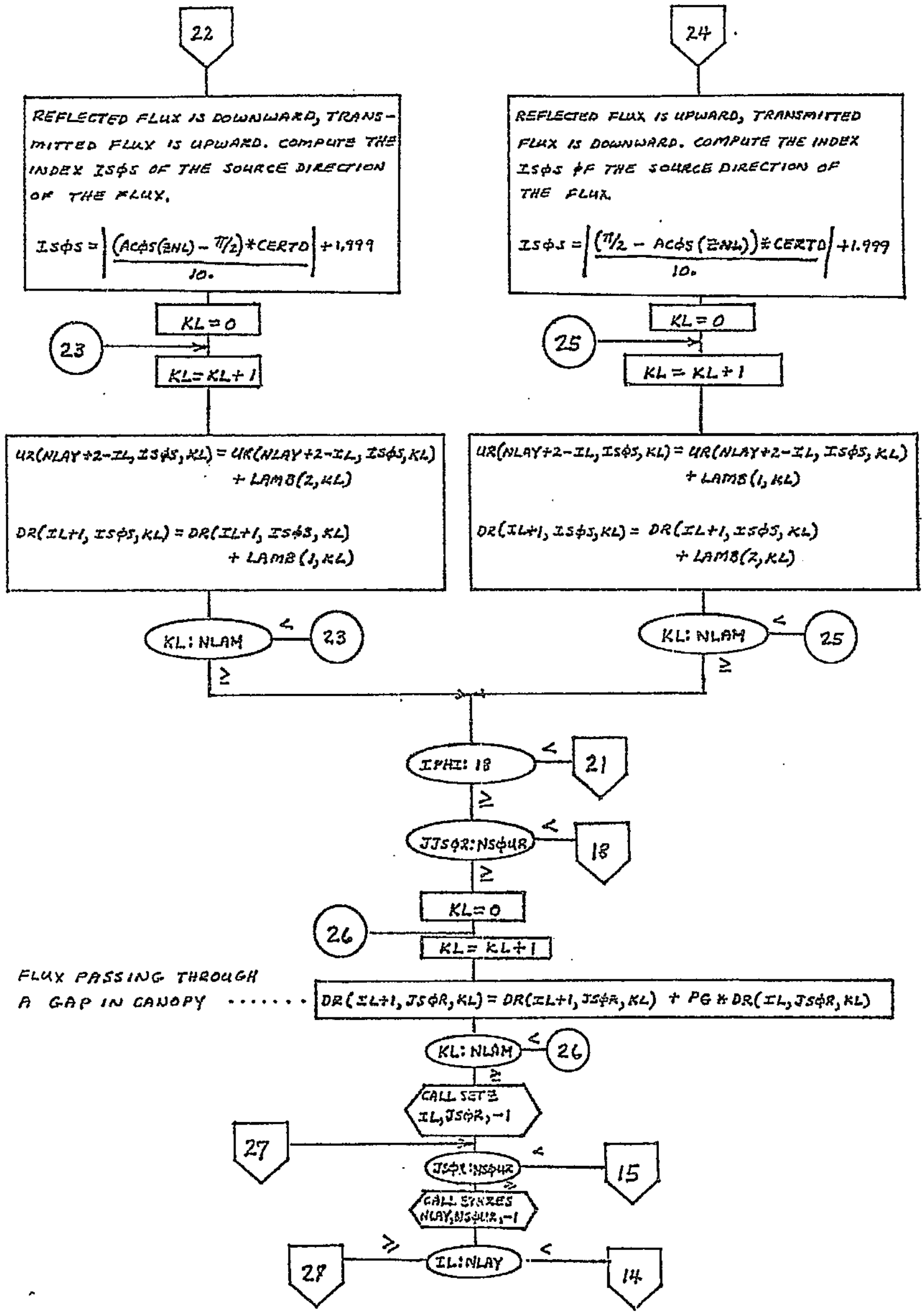


10
IVEC : 1
≤
>
COMPUTE CORRELATION MATRIX COR FOR PRINTING
L : NΦP-1
<
7
≥
BEGIN BIG LOOP
NTRY = 0
11
NTRY = NTRY + 1
WANT NEW RANDΦM RADIATION SOURCE VECTORS EACH PASS?
NTRY : 1
≠
=
ISTΦH : 0
No =
≠ Yes
12
SET SKYIM AND DIFIM. USE THE VECTORS IN XMU IF THERE WAS ΦNLY 1 VECTOR IN THE SET. IF THERE WAS MORE THAN 1 VECTOR THEN CALL NRM (C(1,1,I), XMU(1,I), AVEC) FOR A RANDOM VECTOR
SΦURCE (1,J) = 1 / (1 + DIFIM(J) / CONS [SKYIM(J) - DIFIM(J)])
D = 1 - SΦURCE(1,J)
SΦURCE (I+1, J) = D * XK(I) , I = 1, NBANDS
REPEAT FOR ALL J = 1, NLAM
COMPUTE PROPORTION OF IRRADIANCE WHICH IS DIRECT AND PROPORTION WHICH IS DIFFUSE.
12

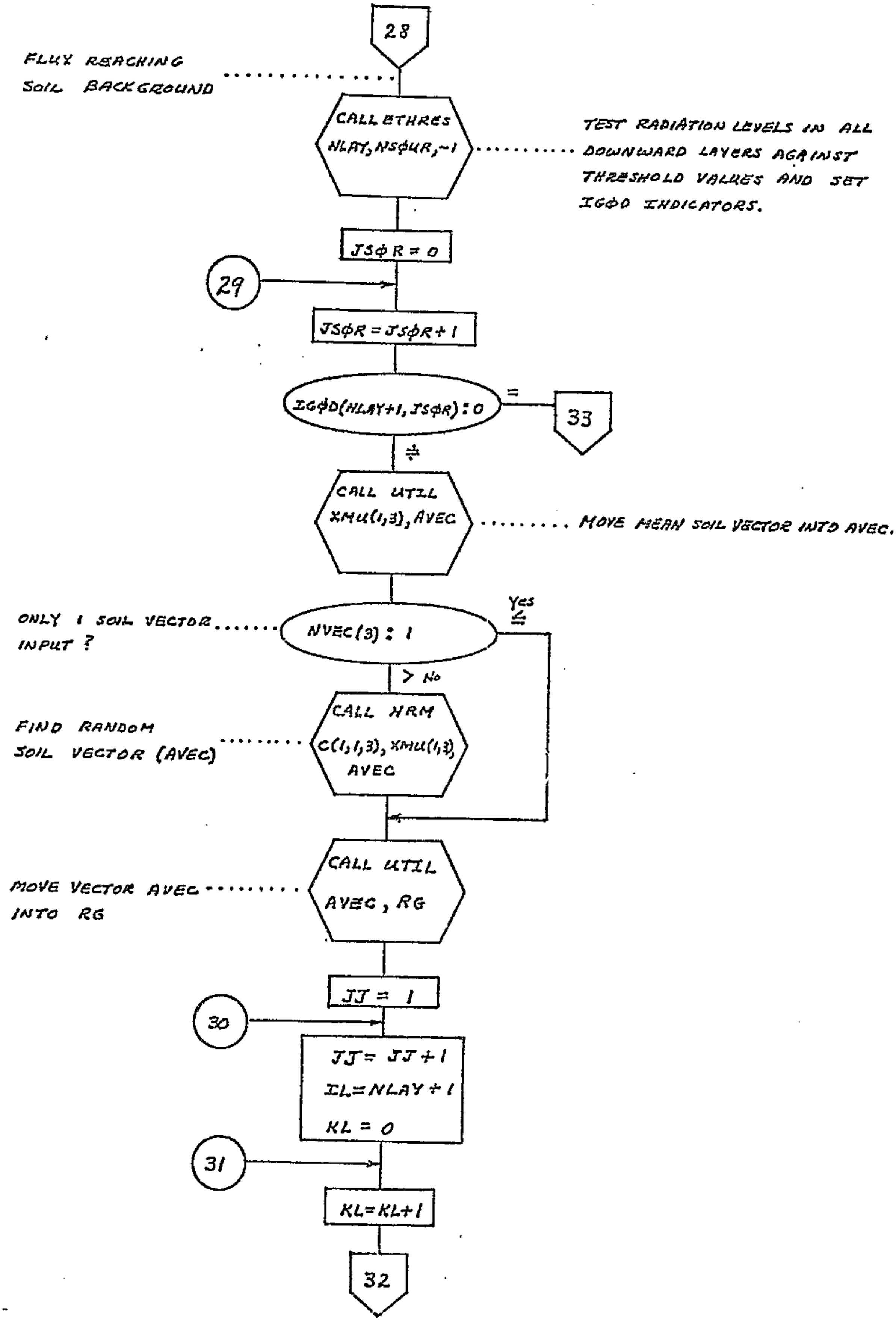

12
SET ARRAYS REFER, DR, UR, IGФD, IGФU TO ZERФ.
DR(1, J, K) = SФURCE(J, K)
J = 1, NSФUR
K = 1, NLAM
INITIALIZE RADIATION FLUX SOURCES AT LAYER 1 OF DOWN GOING SEQUENCE
CALL ETHRES
NLAY, NSФUR, -1
TEST RADIATION LEVELS IN ALL DOWNWARD LAYERS AGAINST THRESHOLD VALUES AND SET IGФD INDICATORS
REFER(KL) = Σ (JSФR=1 to NSФUR) SФURCE(JSФR, KL) * SIN [THETA(JSФR)] * SIN² (FФV/2.)
KL = 1, NLAM
TOTAL INCOMING FLUX REFLECTED FROM A LAMBERTIAN REFLECTOR AND DETECTED BY A VERTICAL SENSOR
13
IDIR = -1
IL = 0
14
DOWNWARD LAYERS
IL = IL+1
JSФR = 0
15
JSФR = JSФR+1
IGФD(IL, JSФR) : 0
=
27
≠
CALL PGAP (IL, JSФR, MTYPE, PHT, NLAY, IDIR)
DETERMINE THE PROPORTION OF LIGHT (PHT) WHICH INTERACTS IN LAYER IL AND THE TYPE OF MATERIAL (MTYPE) HIT BY THIS SOURCE.
IPHIP = 0
PG = 1 - PHT
PG IS THE PROPORTION OF GAP
16
IPHIP = IPHIP+1
CALL LANGLE (IL, MTYPE, THETAL, PHIL)
DETERMINE RANDOM THETAL & PHIL, SINL, CФSL, SINP, CФSP, XLF, YLF, ZLF, and XMATIR, XMATIT
17

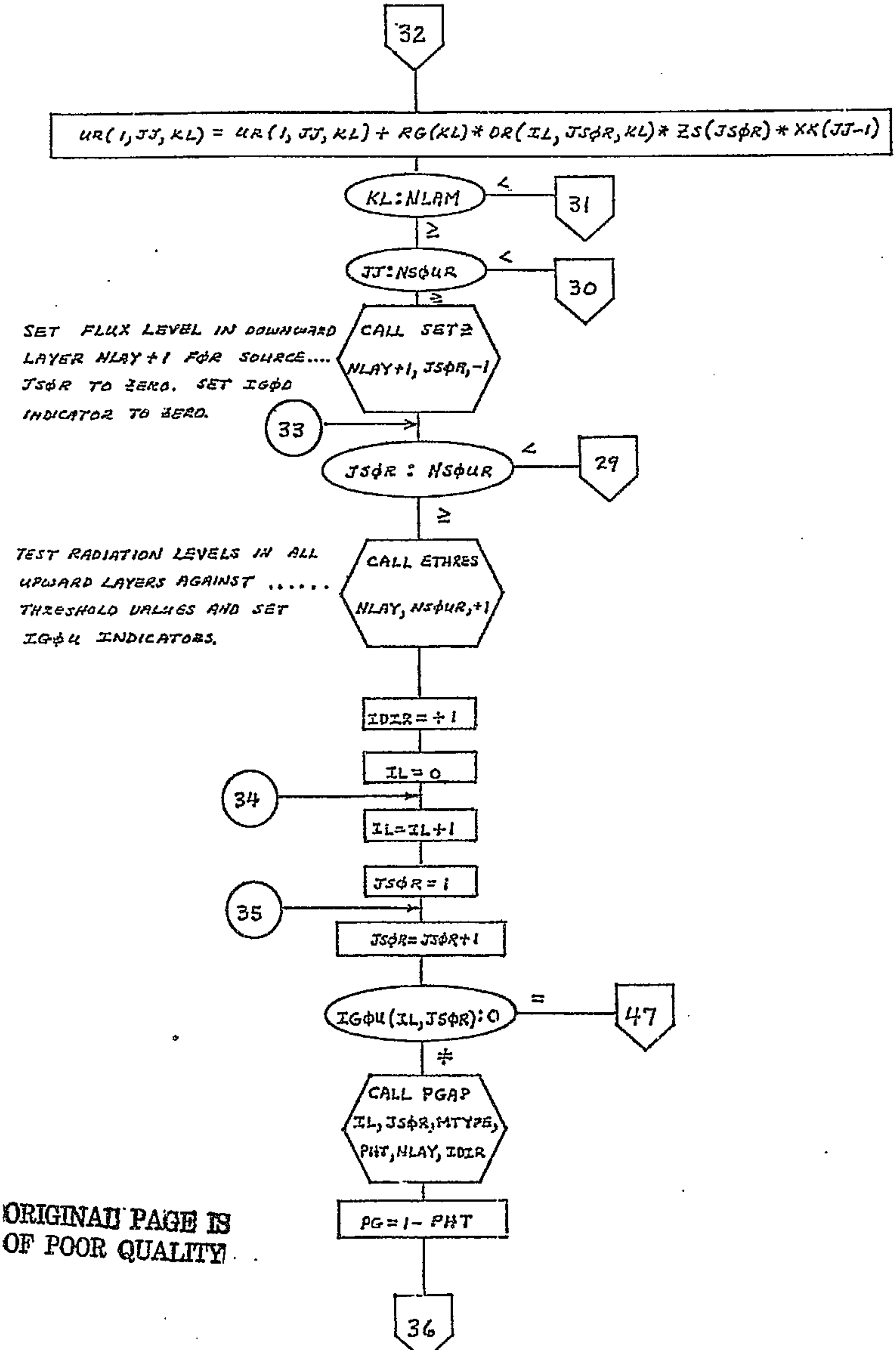


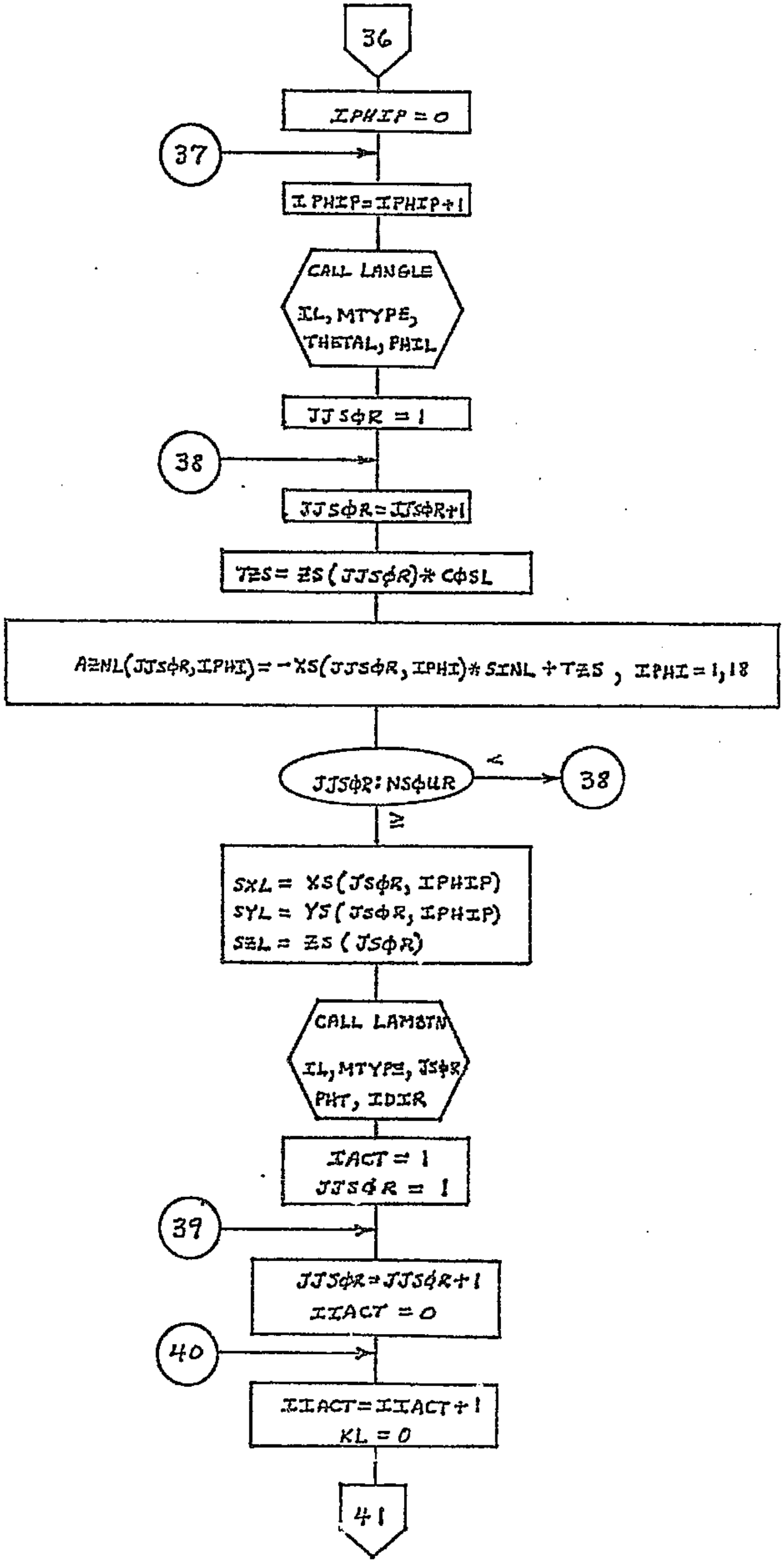
17
TZS = ZS(JJSφR) * CφSL
AZNL(JJSφR,IPHI) = -XS(JJSφR,IPHI) * SINL + TZS , IPHI=1,18
JJSφR = 2,NSφUR
SXL = XS(JSφR, IPHIP)
SYL = YS(JSφR, IPHIP)
SZL = ZS(JSφR)
DIRECTION CφSINES OF SOURCE FLUX
CALL LAMBTH (IL,MTYPE,JSφR, PHT,IDIR)
COMPUTES XLAMB MATRIX WHICH CONTAINS 1/18 THE AMOUNT OF FLUX REFLECTED & TRANSMITTED φF 1/18 THE SOURCE
JJSφR = 1 , IACT = 1
18
JJSφR = JJSφR+1
IIACT = 0
19
IIACT = IIACT+1
KL = 0
20
KL = KL + 1
LAMB(IIACT,KL) = XLAMB(IIACT,KL) * XK(JJSφR-1)
KL:NLAM
<
20
≥
IIACT:2
<
19
≥
IPHI = 0
21
IPHI = IPHI + 1
ZNL = AZNL(JJSφR,IPHI)
ZNL:0
≥
24
<
22

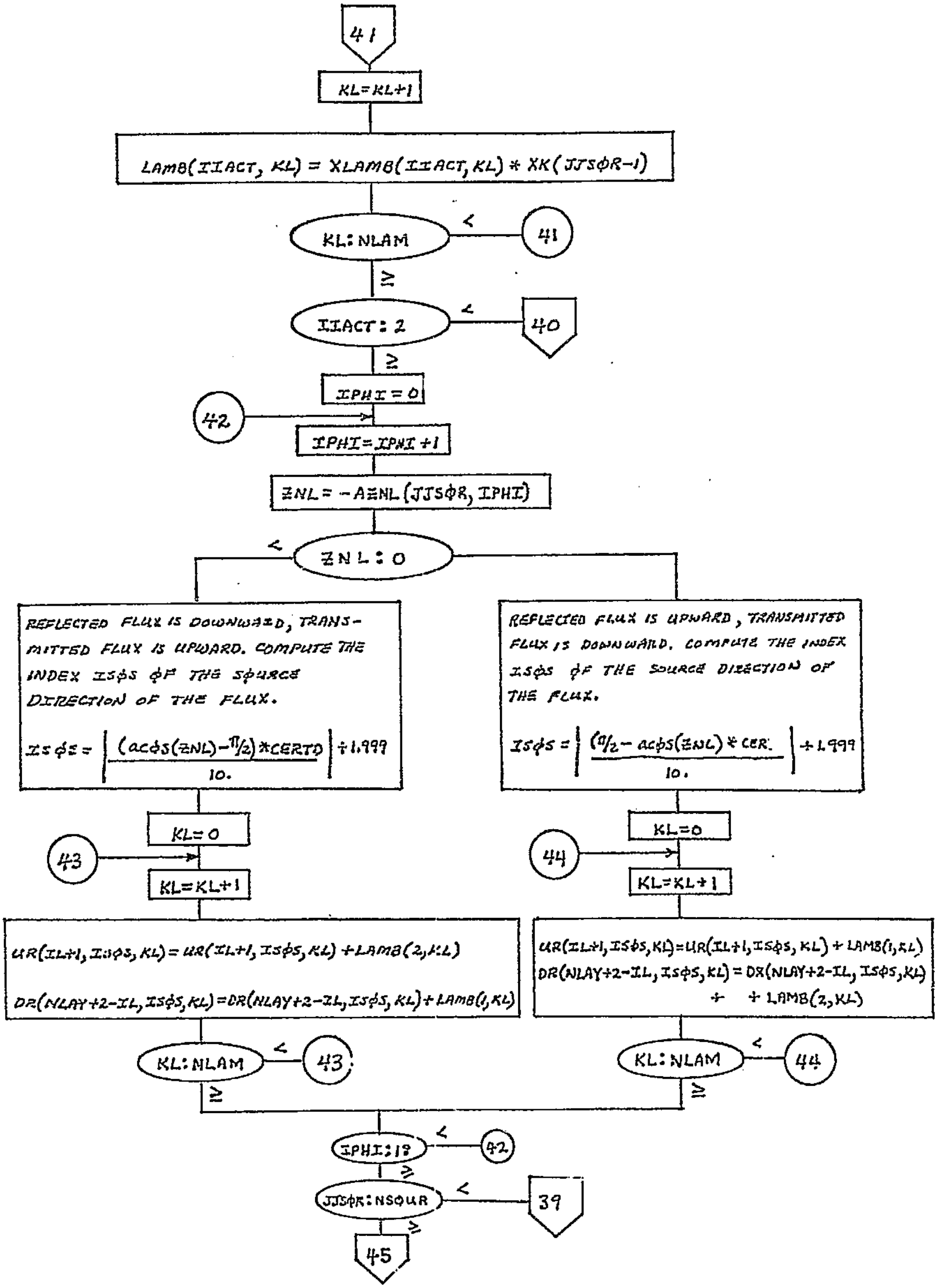


22
24
REFLECTED FLUX IS DOWNWARD, TRANSMITTED FLUX IS UPWARD. COMPUTE THE INDEX ISØS OF THE SOURCE DIRECTION OF THE FLUX.
ISØS = |(ACØS(ZNL) − π/2)*CERTD / 10.| + 1.999
REFLECTED FLUX IS UPWARD, TRANSMITTED FLUX IS DOWNWARD. COMPUTE THE INDEX ISØS ØF THE SOURCE DIRECTION OF THE FLUX.
ISØS = |(π/2 − ACØS(ZNL))*CERTD / 10.| + 1.999
KL = 0
23
KL = KL + 1
KL = 0
25
KL = KL + 1
UR(NLAY+2−IL, ISØS, KL) = UR(NLAY+2−IL, ISØS, KL) + LAMB(2, KL)
DR(IL+1, ISØS, KL) = DR(IL+1, ISØS, KL) + LAMB(1, KL)
UR(NLAY+2−IL, ISØS, KL) = UR(NLAY+2−IL, ISØS, KL) + LAMB(1, KL)
DR(IL+1, ISØS, KL) = DR(IL+1, ISØS, KL) + LAMB(2, KL)
KL: NLAM
<
23
≥
KL: NLAM
<
25
≥
IPHI: 18
<
21
≥
JJSØR: NSØUR
<
18
≥
KL = 0
26
KL = KL + 1
FLUX PASSING THROUGH A GAP IN CANOPY
DR(IL+1, JSØR, KL) = DR(IL+1, JSØR, KL) + PG * DR(IL, JSØR, KL)
KL: NLAM
<
26
≥
CALL SETZ IL, JSØR, −1
27
JSØR: NSØUR
<
15
≥
CALL SYMZES NLAY, NSØUR, −1
28
≥
IL: NLAY
<
14

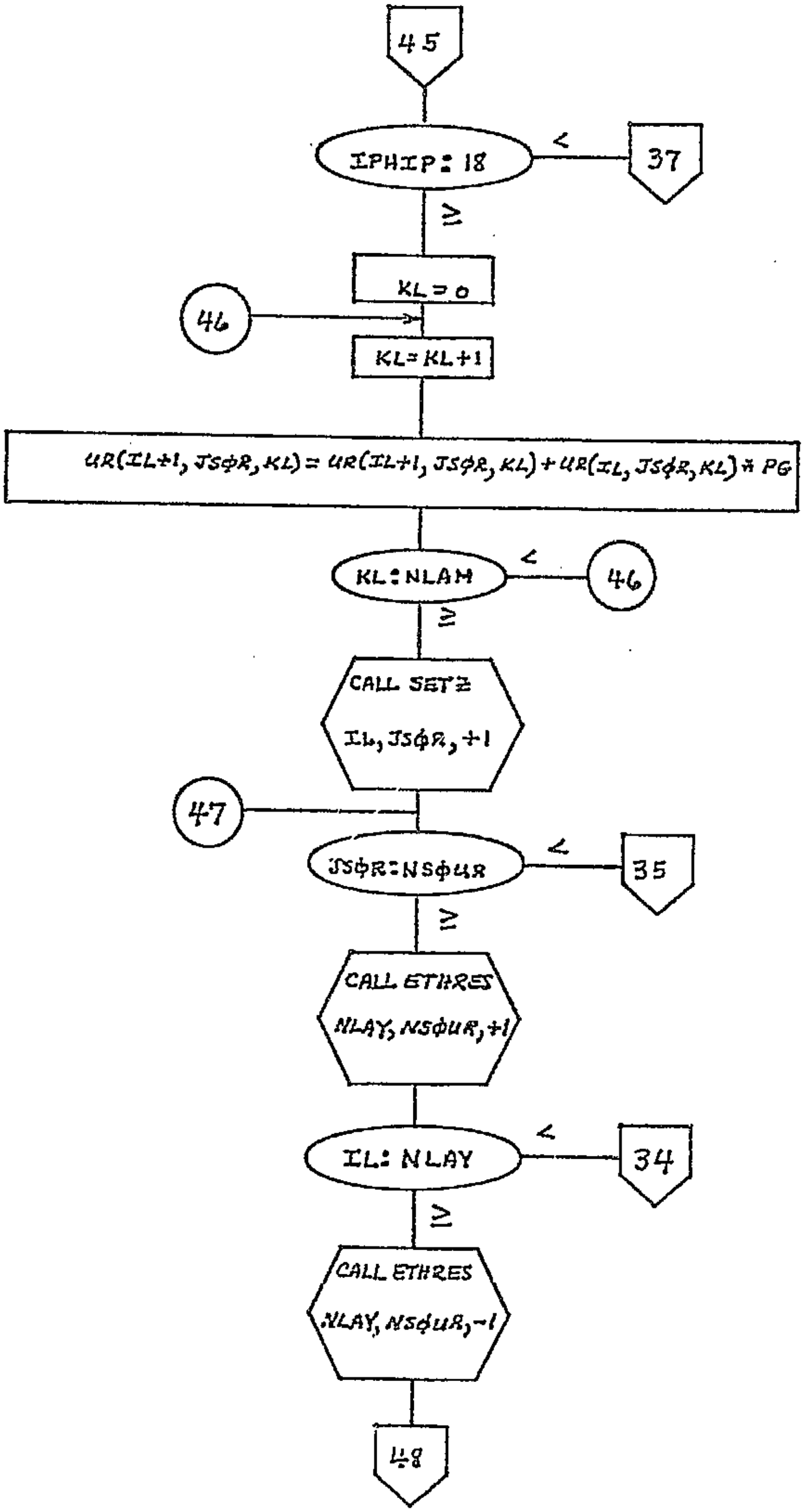

28
FLUX REACHING SOIL BACKGROUND
CALL ETHRES NLAY, NSØUR, -1
TEST RADIATION LEVELS IN ALL DOWNWARD LAYERS AGAINST THRESHOLD VALUES AND SET IGØD INDICATORS.
JSØR = 0
29
JSØR = JSØR + 1
IGØD(NLAY+1, JSØR) : 0
=
33
≠
CALL UTIL XMU(1,3), AVEC
MOVE MEAN SOIL VECTOR INTO AVEC.
ONLY 1 SOIL VECTOR INPUT ?
NVEC(3) : 1
Yes ≤
> No
FIND RANDOM SOIL VECTOR (AVEC)
CALL HRM C(1,1,3), XMU(1,3), AVEC
MOVE VECTOR AVEC INTO RG
CALL UTIL AVEC, RG
JJ = 1
30
JJ = JJ + 1
IL = NLAY + 1
KL = 0
31
KL = KL + 1
32

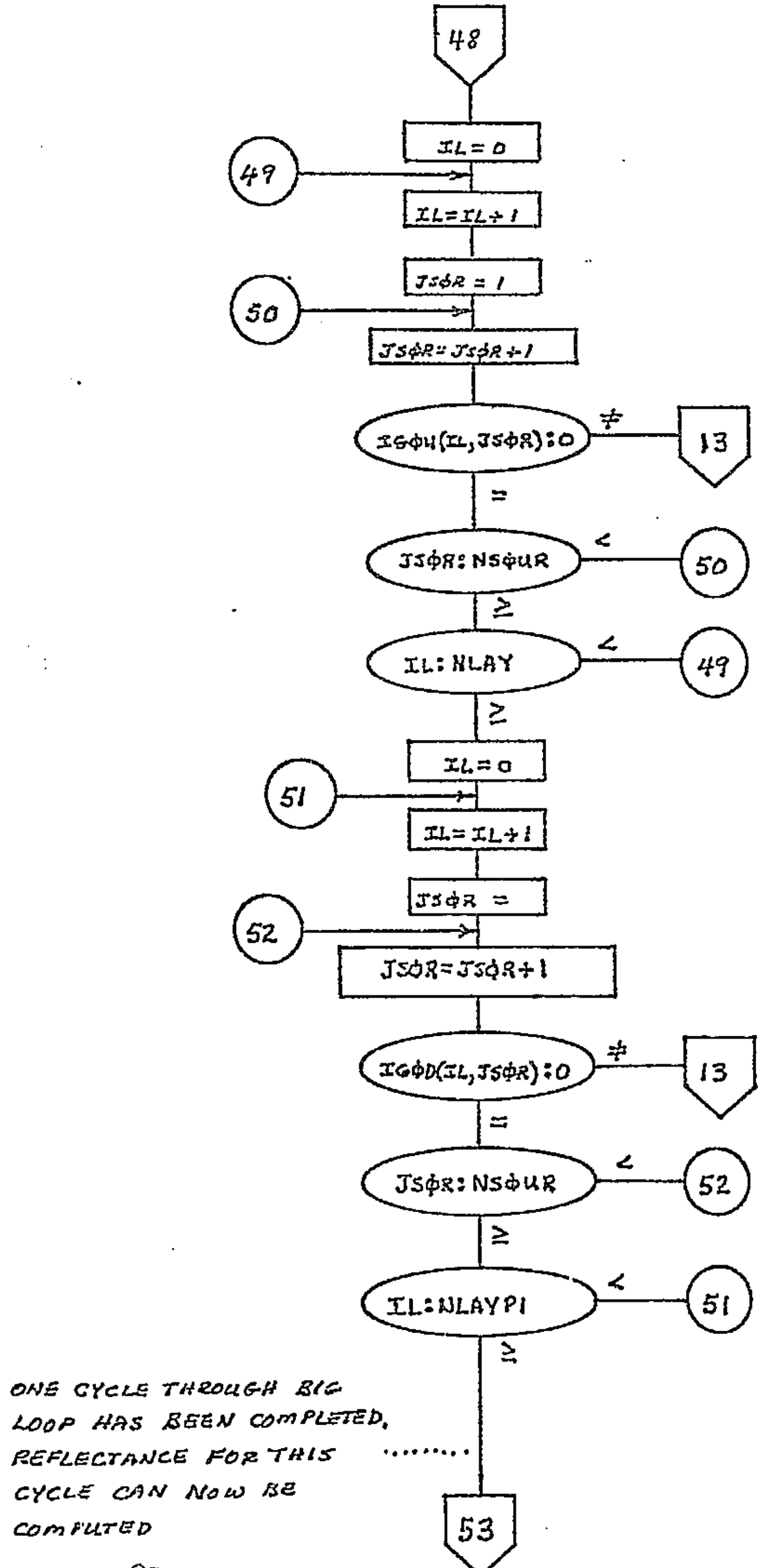

32
UR(1,JJ,KL) = UR(1,JJ,KL) + RG(KL)*DR(IL,JSØR,KL)*ZS(JSØR)*XK(JJ-1)
KL:NLAM
<
31
≥
JJ:NSØUR
<
30
≥
SET FLUX LEVEL IN DOWNWARD LAYER NLAY+1 FØR SOURCE.... JSØR TO ZERO. SET IGØD INDICATOR TO ZERO.
CALL SETZ
NLAY+1, JSØR, -1
33
JSØR : NSØUR
<
29
≥
TEST RADIATION LEVELS IN ALL UPWARD LAYERS AGAINST ...... THRESHOLD VALUES AND SET IGØU INDICATORS.
CALL ETHRES
NLAY, NSØUR, +1
IDIR = +1
IL = 0
34
IL=IL+1
JSØR = 1
35
JSØR= JSØR+1
IGØU(IL,JSØR):0
=
47
≠
CALL PGAP
IL, JSØR, MTYPE,
PHT, NLAY, IDIR
PG = 1- PHT
36

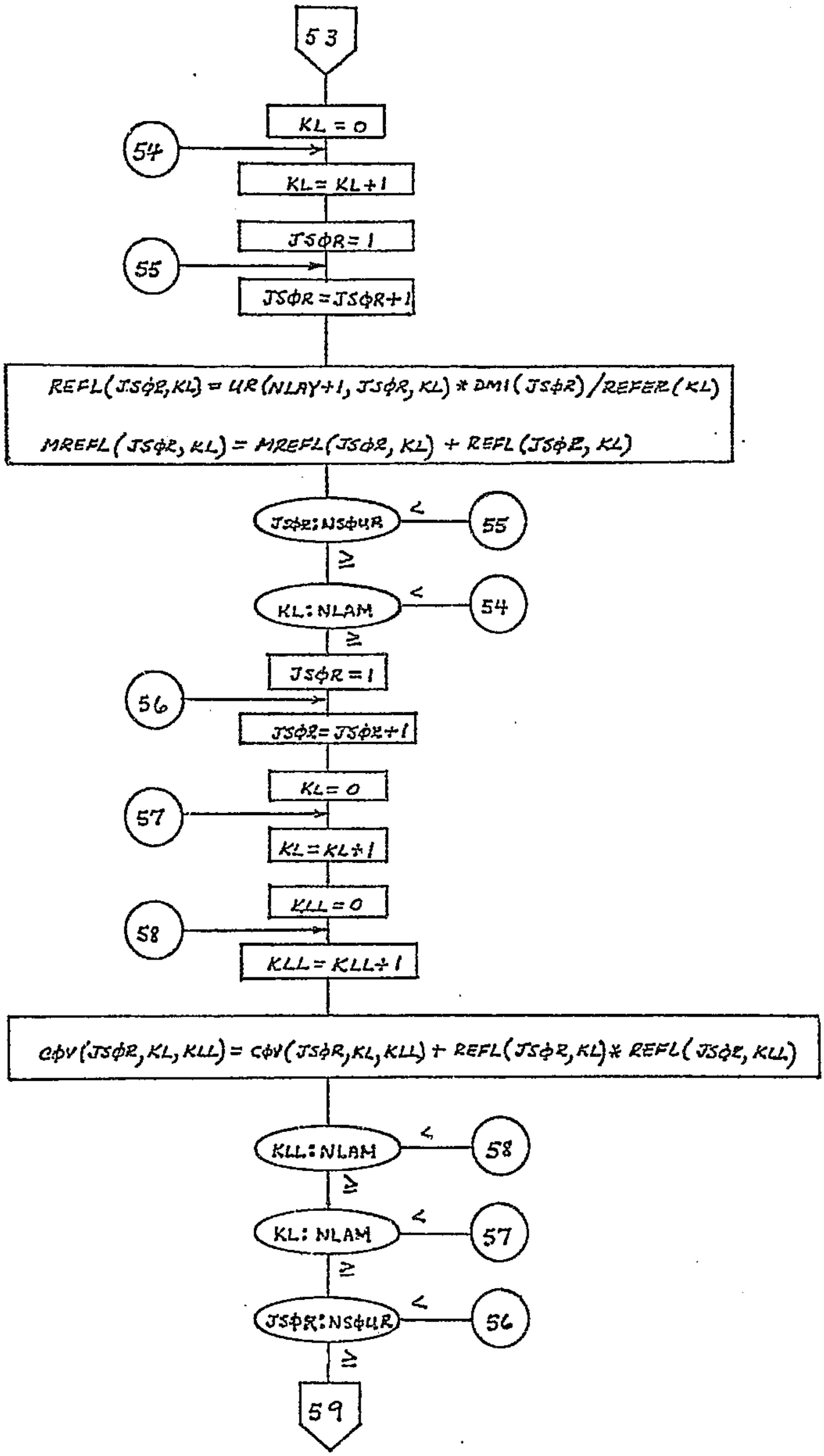

36
IPHIP = 0
37
IPHIP=IPHIP+1
CALL LANGLE
IL, MTYPE, THETAL, PHIL
JJSφR = 1
38
JJSφR=JJSφR+1
TZS= ZS(JJSφR)* CφSL
AZNL(JJSφR,IPHI)= -XS(JJSφR,IPHI)* SINL +TZS , IPHI=1,18
JJSφR: NSφUR
<
38
≥
SXL = XS(JSφR, IPHIP)
SYL = YS(JSφR, IPHIP)
SZL = ZS (JSφR)
CALL LAMBTN
IL, MTYPE, JSφR
PHT, IDIR
IACT = 1
JJSφR = 1
39
JJSφR=JJSφR+1
IIACT = 0
40
IIACT=IIACT+1
KL = 0
41

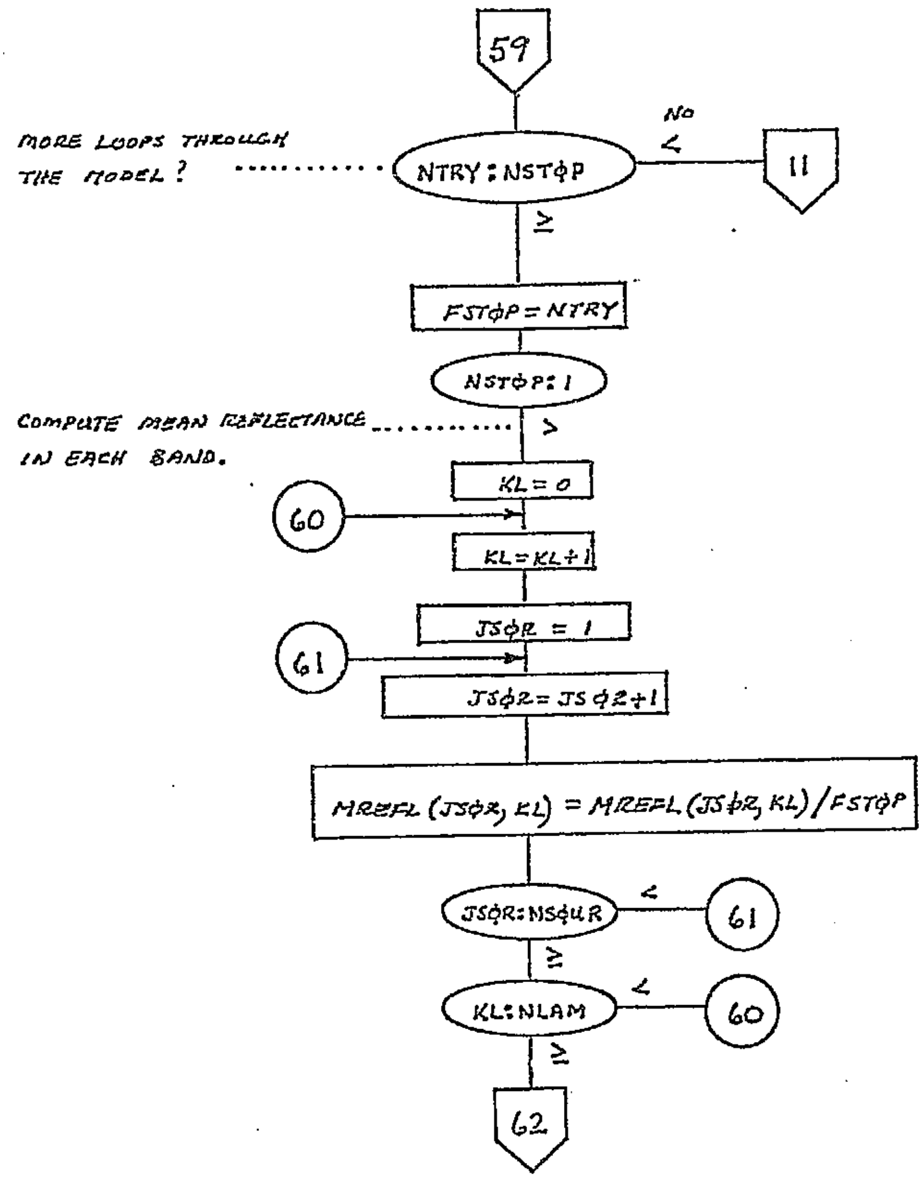


41
KL=KL+1
LAMB(IIACT, KL) = XLAMB(IIACT, KL) * XK(JJSØR-1)
KL: NLAM
<
41
≥
IIACT: 2
<
40
≥
IPHI = 0
42
IPHI=IPHI +1
ZNL = -AZNL (JJSØR, IPHI)
ZNL: 0
<
REFLECTED FLUX IS DOWNWARD, TRANS-MITTED FLUX IS UPWARD. COMPUTE THE INDEX ISØS OF THE SOURCE DIRECTION OF THE FLUX.
ISØS = | (ACØS(ZNL)-π/2)*CERTD / 10. | +1.999
REFLECTED FLUX IS UPWARD, TRANSMITTED FLUX IS DOWNWARD. COMPUTE THE INDEX ISØS OF THE SOURCE DIRECTION OF THE FLUX.
ISØS = | (π/2 - ACØS(ZNL) * CER. / 10. | +1.999
KL=0
43
KL=KL+1
UR(IL+1, ISØS, KL) = UR(IL+1, ISØS, KL) +LAMB(2,KL)
DR(NLAY+2-IL, ISØS, KL) = DR(NLAY+2-IL, ISØS, KL) + LAMB(1,KL)
KL=0
44
KL=KL+1
UR(IL+1, ISØS, KL)=UR(IL+1, ISØS, KL) + LAMB(1,KL)
DR(NLAY+2-IL, ISØS, KL) = DR(NLAY+2-IL, ISØS, KL)
+ + LAMB(2,KL)
KL: NLAM
<
43
≥
KL: NLAM
<
44
≥
IPHI: 19
<
42
≥
JJSØR: NSOUR
<
39
≥
45

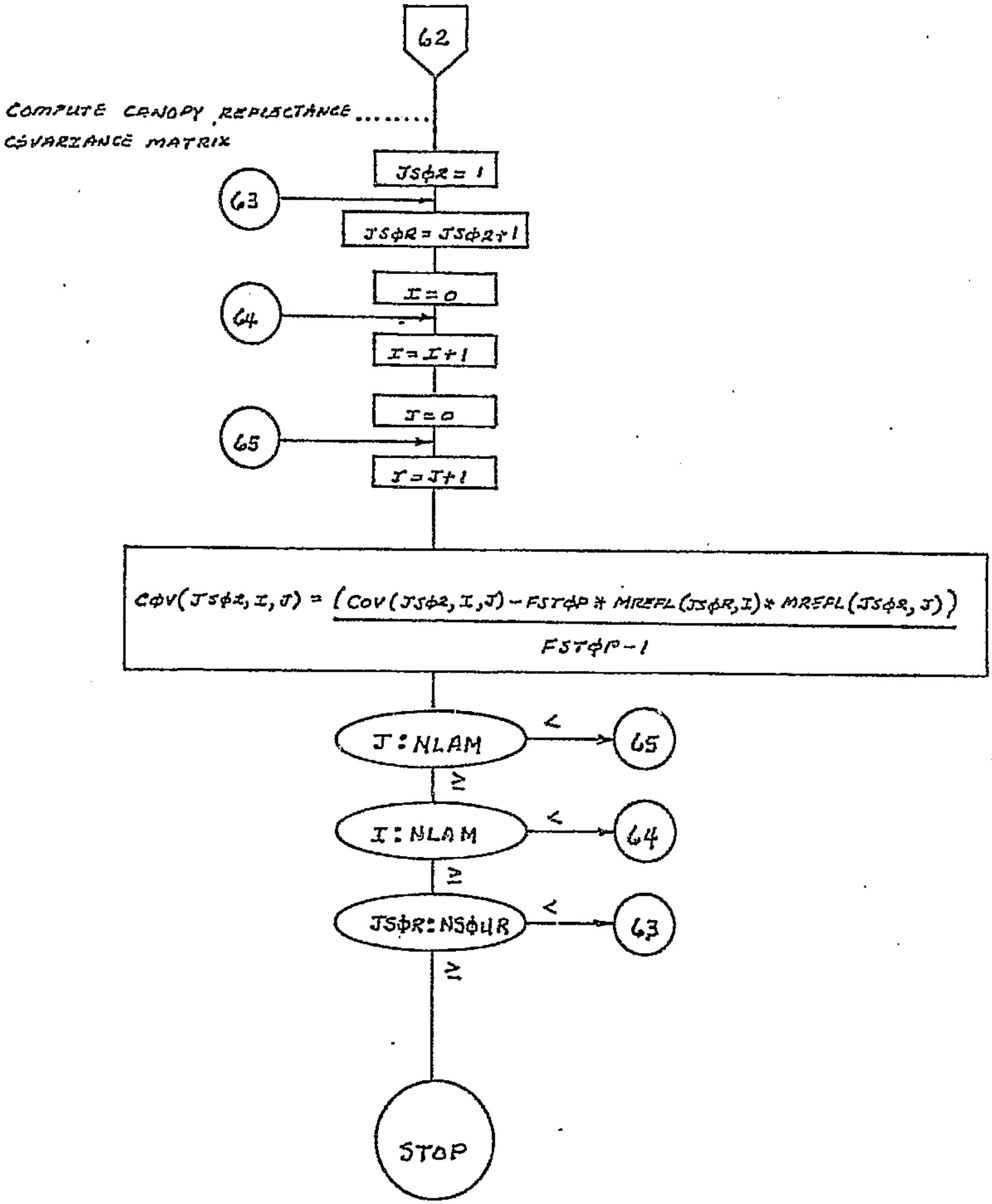

45
IPHIP: 18
<
37
≥
KL = 0
46
KL = KL+1
UR(IL+1, JSØR, KL) = UR(IL+1, JSØR, KL) + UR(IL, JSØR, KL) * PG
KL: NLAM
<
46
≥
CALL SETZ
IL, JSØR, +1
47
JSØR: NSØUR
<
35
≥
CALL ETHRES
NLAY, NSØUR, +1
IL: NLAY
<
34
≥
CALL ETHRES
NLAY, NSØUR, -1
48


48
IL = 0
49
IL=IL+1
JSØR = 1
50
JSØR=JSØR+1
IGØU(IL,JSØR):0
≠
13
=
JSØR:NSØUR
<
50
≥
IL:NLAY
<
49
≥
IL=0
51
IL=IL+1
JSØR =
52
JSØR=JSØR+1
IGØD(IL,JSØR):0
≠
13
=
JSØR:NSØUR
<
52
≥
IL:NLAYP1
<
51
≥
ONE CYCLE THROUGH BIG LOOP HAS BEEN COMPLETED, REFLECTANCE FOR THIS CYCLE CAN NOW BE COMPUTED
53


53
KL = 0
54
KL = KL+1
JSφR = 1
55
JSφR = JSφR+1
REFL(JSφR,KL) = UR(NLAY+1, JSφR, KL) * DM1(JSφR)/REFER(KL)
MREFL(JSφR, KL) = MREFL(JSφR, KL) + REFL(JSφR, KL)
JSφR:NSφUR
<
55
≥
KL: NLAM
<
54
≥
JSφR = 1
56
JSφR = JSφR+1
KL = 0
57
KL = KL+1
KLL = 0
58
KLL = KLL+1
CφV(JSφR,KL,KLL) = CφV(JSφR,KL,KLL) + REFL(JSφR,KL) * REFL(JSφR,KLL)
KLL: NLAM
<
58
≥
KL: NLAM
<
57
≥
JSφR:NSφUR
<
56
≥
59



59
MORE LOOPS THROUGH THE MODEL?
NTRY : NSTØP
No
<
11
≥
FSTØP = NTRY
NSTØP : 1
COMPUTE MEAN REFLECTANCE IN EACH BAND.
>
KL = 0
60
KL = KL + 1
JSØR = 1
61
JSØR = JSØR + 1
MREFL (JSØR, KL) = MREFL (JSØR, KL) / FSTØP
JSØR : NSØUR
<
61
≥
KL : NLAM
<
60
≥
62


62
COMPUTE CANOPY REFLECTANCE
COVARIANCE MATRIX
JSØR = 1
63
JSØR = JSØR + 1
I = 0
64
I = I + 1
J = 0
65
J = J + 1
CØV(JSØR, I, J) = (COV(JSØR, I, J) − FSTØP * MREFL(JSØR, I) * MREFL(JSØR, J)) / (FSTØP − 1)
J : NLAM
<
65
≥
I : NLAM
<
64
≥
JSØR : NSØUR
<
63
≥
STOP

```
      PROGRAM SRVC(INPUT,OUTPUT,FILMPL,PUNCH,DSET72,TAPE1,
     1TAPE6=OUTPUT,TAPE5=INPUT)
C.... SOLAR RADIATION - VEGETATION CANOPY REFLECTANCE MODEL
C.... THIS PROGRAM CALCULATES THE APPARENT DIRECTIONAL REFLECTANCE OF A
C.... VEGETATION CANOPY AS A FUNCTION OF CANOPY GEOMETRY, LEAF REFLEC-
C.... TANCE AND TRANSMISSION, SOIL REFLECTANCE, AND CANOPY IRRADIANCE
C.... FOR A GIVEN SOLAR POSITION.
C.... R.E. OLIVER AND J.A. SMITH  COLORADO STATE UNIVERSITY  JUNE, 1974
C
C................... COMMON BLOCKS AND REFERENCES ...................
C
C     LABEL    EXTERNAL REFERENCES
C
C      C1        BLOCK DATA, LAMBTN, SUN, ETHRES, LANGLE, NRM, SETZ, UTIL,
C                AND COP.
C
C      C2        LAMBTN, PDENS, AND OPTICAL.
C
C      C4        LANGLE, PDENS, AND PGAP.
C
C      C6        ETHRES, SETZ, AND LAMBTN.
C
C      C8        LANGLE.
C
C      L1        OPTICAL.
C
C      CMAT      PGAP AND LAMBTN
C
C      //        LANGLE AND LAMBTN.
C
      COMMON/C1/DAY,YEAR,TIME,GLAT,GLONG,DEC,RANDW,NLAM,THETS1,THETS2,
     1NMAT,EXTRA(4),NOP,INIT,DUM1(13),
     2CEDIR,CERTD,CEMTR,CERIO2,CE1PI,CE2PI,DUM2(14),
     3SINLAT,COSLAT,SINDEC,COSDEC,COSH,SINZ,COSZ,SINAZ,COSAZ,LXS,LYS,LZS
      COMMON/C2/CANRM(17),SKYIM(17),DIFIM(17),XMAT1R(17)
     1,XMAT1T(17),XMAT2R(17),XMAT2T(17),XMAT3R(17),XMAT3T(17),RG(17),
     2XLAM(17),SOURCE(10,17),THETA(10),ZENITH(10)
      COMMON/C4/RANGLF(3,3),FLA(3,3,10),SLAI(3,3),FLAT(3,3),PHIT(3,3,10)
      COMMON/C6/DR(4,10,17),UR(4,10,17),THRESD(10),IGOD(4,10),IGOU(4,10)
     1,THRESU(10)
      COMMON/C8/SINL,COSL,SINP,COSP
      COMMON/L1/DATAIC(7,9),XMU(17,9),C(17,17,9),NVEC(9)
      COMMON/CMAT/MTP(3),NLAY,OPM(10)
     A,ENDLC
      COMMON AVEC(17),XK(9),SXL,SYL,SZL,XLF,YLF,ZLF
     1,XS(10,18),YS(10,18),ZS(10)
     A,ENDBR
C.......................... INTERNAL ARRAYS ..........................
      DIMENSION JOBID(8),VECT(17),SIG(17),V(17,17),COR(17,17)
      DIMENSION COV(10,17,17),COVM(17,17)
      DIMENSION YLFA(19),YLFA(19),DM(17),DM1(17),REFER(17)
      DIMENSION RIT(10,17),RITBAR(10,17),RBAR(10,17)
      DIMENSION F(19),OP(9)
      REAL LXS,LYS,LZS,INCLF
      INTEGER DAY,YEAR,TH,TM,ZDEG
 9000 CALL SETC(0.,CANRM(1),ENDLC)
      CALL SETC(0.,AVEC(1),ENDBR)
      CALL SETC(0.,JOBID(1),OP(9))
C....PERIPHERAL CONTROLS
```

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OF POOR QUALITY

```
      IHIST = 0
      ISTOP = 1
      IFILE = 5
C     READ(5,102) IFILE
      IF(EOF(5).NE.0.) STOP
      IF(IHIST.EQ.1) CALL FUN(-1,-1)
C....GENERAL SIMULATION CONSTRAINTS
      READ(IFILE,100) JOBID,DAY,YEAR,TH,TM,GLAT,GLONG,DEC,NBANDS,
     1NLAM,NMAT,INIT,NSAMP,NTRIAL
      IF(EOF(5).NE.0.) STOP
      READ(IFILE,102) NLAY
      BANDW=90/NBANDS
      WRITE(6,200) JOBID,DAY,YEAR,TH,TM,GLAT,GLONG,DEC,BANDW,NLAM,NMAT,
     1INIT,NSAMP,NTRIAL,NLAY
      READ(IFILE,101) THRESD $READ(IFILE,101) THRESU
      WRITE(6,221) THRESD,THRESU
C....PARAMETER INITIALIZATION AND CONVERSION
      NSOUR=NBANDS+1
      NLAYP1=NLAY+1
      FOV=2.*CEDTR
      FOV02=FOV/2.0
      SINFOV=SIN(FOV02)
      CALL RANSET(INIT)
      XT1=TH
      XT2=TM
      TIME=XT1+(XT2/60.)
      GLAT=GLAT*CEDTR
      GLONG=GLONG*CEDTR
      DEC=DEC*CEDTR
      BANDW=BANDW*CEDTR
C....SUN POSITION PARAMETERS
      CALL SUN
      WRITE(6,222) LXS,LYS,LZS
      ZS(1) = LZS
C....COEFFICIENTS FOR DIFFUSE RADIATION VECTORS
C....SENSOR/BAND AREA RATIO FOR ALL DIFFUSE BANDS
      ALPHA2=0.
      SINA2=0.
      DO 2 I=1,NBANDS
      SINA1=SINA2
      ALPHA2=ALPHA2+BANDW
      SINA2=SIN(ALPHA2)
      XK(I)=SINA2*SINA2-SINA1*SINA1
    2 DM1(I+1)=SINFOV*SINFOV/XK(I)
      WRITE(6,208) (XK(I),I=1,NBANDS)
      WRITE(6,212) (DM1(I),I=2,NSOUR)
C....SOURCE DIRECTION INCLINATION ANGLES
      TOTAL=0.
      THETA(1)=(BANDW/2.)-BANDW
      DO 3 I=1,NBANDS
      THETA(I+1)=THETA(I)+BANDW
    3 TOTAL=TOTAL+(XK(I)/SIN(THETA(I+1)))
      THETA(1)=CEPIO2-ACOS(COSZ)
      CONS=LZS*TOTAL
      DO 50 I=1,10
   50 ZENITH(I)=CEPIO2-THETA(I)
      WRITE(6,223) THETA
C....DIRECTION COSINES OF AZIMUTHAL SECTORS IN THE DIFFUSE BANDS
      DEG20=20.*CEDTR
```

2

```
      DO 60 JSOR=2,NSOUR
      ZS(JSOR)=SIN(THETA(JSOR))
      PHI=1 .*CEDTR
      DO 60 IPHI=1,18
      XS(JSOR,IPHI)=COS(THETA(JSOR))*COS(PHI)
      YS(JSOR,IPHI)=COS(THETA(JSOR))*SIN(PHI)
   60 PHI=PHI+DEG20
C....CANOPY GEOMETRY.  EACH CANOPY LAYER IS COMPOSED OF ONE OPTICAL
C....MATERIAL WHICH MAY BE SPECIFIED AND UNIQUE GEOMETRICAL PROPERTIES.
C....CANOPY GEOMETRIC PARAMETERS CONSIST OF (1)LEAF ANGLE FREQUENCY
C....DISTRIBUTION FUNCTION DENOTED BY XLFA AND YLFA (2)LEAF AREA INDEX
C....DENOTED BY FLAI AND (3)CANOPY DENSITY DENOTED BY SLAI.  XLFA (DEG)
C....AND YLFA MUST BE SPECIFIED AT AN ODD NUMBER (NANG) OF EVENLY SPACED
C....POINTS.  FLAI IS NON-NEGATIVE AND SLAI RANGES BETWEEN 0 AND 1.
      DELF=10.*CEDTR
      WRITE(6,227)
      DO 350 IL=1,NLAY
      READ(IFILE,102) NANG
      READ(IFILE,102) IMAT
      MTF(IL) = IMAT
      READ(IFILE,101) (XLFA(I),YLFA(I),I=1,NANG)
      READ(IFILE,101) SLAI(IL,IMAT),FLAI(IL,IMAT)
C....INTEGRATE AND NORMALIZE THE LEAF ANGLE FREQUENCY DISTRIBUTION
C....FUNCTION USING SIMPSONS RULE--THIS IS TEMPORARILY DENOTED BY F.
C....M-1 EQUALLY SPACED INTERVALS OF F ARE THEN DETERMINED AND DENOTED
C....BY FLA (M POINTS).  THE TABLE FLA IS USED FOR RANDOMLY SELECTING
C....LEAF INCLINATION ANGLES.
      DO 305 I=1,NANG
305   XLFA(I)=XLFA(I)*CEDTR
      M=((NANG-1)/2)+1
      NANGLE(IL,IMAT)=M
      CALL TBLE(M,XLFA,YLFA,DM,F)
      WRITE(6,233) (F(I),I=1,M)
      DO 310 IANG=1,M
  310 FLA(IL,IMAT,IANG)=DM(IANG)
C....NORMALIZE THE INPUT LEAF FREQUENCY DISTRIBUTION FUNCTION TO OBTAIN
C....A DENSITY FUNCTION F WHICH IS SPECIFIED AT M POINTS.
      FTOT= .
      DO 311 I=1,NANG
  311 FTOT=FTOT+YLFA(I)
      DO 312 I=1,9
  312 F(I)=(YLFA(2*I)+YLFA(2*I+1))/FTOT
      DO 315 I=1,NANG
315   XLFA(I)=XLFA(I)*CERTD
      WRITE(6,230) IL,IMAT,NANG,(XLFA(I),YLFA(I),I=1,NANG)
      WRITE(6,231) NANGLE(IL,IMAT)
      WRITE(6,232) (FLA(IL,IMAT,I),I=1,M)
      M=M-1
      WRITE(6,233) (F(I),I=1,M)
      WRITE(6,207) FLAI(IL,IMAT),SLAI(IL,IMAT)
C....CALCULATE THE MEAN PROJECTION (OP) IN THE DIRECTION OF THE SOURCE
C...(THETA) OF ONE UNIT LEAF AREA WITH INCLINATION INCLF.  THE LEAVES
C....AT THIS ANGLE ARE ASSUMED TO BE AZIMUTHALLY ISOTROPIC.
      DO 330 IANGLE=1,NSOUR
      INCLF=-5.*CEDTR
      DO 320 I=1,9
      INCLF=INCLF+DELF
  320 CALL COP(INCLF,THETA(IANGLE),OP(I))
C....CALCULATE THE MEAN PROJECTION (OPM) IN THE DIRECTION OF THE SOURCE
```

```
C....(THETA) OF ONE UNIT LEAF AREA AVERAGED OVER THE CANOPY LEAF ANGLE
C....DENSITY FUNCTION F.
      CALL COPM(F,OP,OPM(IANGLE))
C....CALCULATE THE PROBABILITY OF A HIT (PHIT) FOR A LIGHT RAY WITH
C....SOURCE DIRECTION THETA.
      CALL PDENS(IL,IMAT,IANGLE,OPM(IANGLE))
      WRITE(6,235) OP,OPM(IANGLE),PHIT(IL,IMAT,IANGLE)
  330 CONTINUE
  350 CONTINUE
      WRITE(6,228)
C....REFLECTANCE AND TRANSMISSION VECTORS ARE READ FOR EACH CANOPY
C....CONSTITUENT.  IN ADDITION REFLECTANCE VECTORS ARE READ FOR THE SOIL
C....BACKGROUND AND THE MEASURED CANOPY.  THE MEAN VECTOR AND COVARIANCE
C....AND CORRELATION MATRICES ARE CALCULATED AS WELL AS THE SQUARE-ROOT
C....MATRIX WHICH IS SUBSEQUENTLY USED FOR MULTIVARIATE NORMAL
C....STOCHASTIC VECTOR SAMPLING.
C
C....WAVELENGTHS TO BE SIMULATED
      READ(IFILE,101) (XLAM(I),I=1,NLAM)
      WRITE(6,201) (XLAM(I),I=1,NLAM)
C....CONSTITUENT OPTICAL VECTORS
      NOP=2*NMAT+4
      DO 11 L=1,NOP
      NL=L-1
      IF(L.EQ.1) NL=1
      IF(L.EQ.2) CALL SETC(0.,DATAID(1,1),C(17,17,9))
      CALL SETC(0.,V(1,1),V(17,17))
      READ(IFILE,102) NVEC(NL),(DATAID(I,NL),I=1,7)
      IF(L.EQ.1) NM=NVEC(1)
      XVEC=NVEC(NL)
      WRITE(6,202) (DATAID(I,NL),I=1,3),NVEC(NL)
      IVEC=NVEC(NL)
C....READ OPTICAL CONSTITUENT VECTORS
      DO 4 I=1,IVEC
      IF((L.NE.2).AND.(L.NE.3)) READ(IFILE,101) (VECT(J),J=1,NLAM)
      IF((L.EQ.2).OR.(L.EQ.3)) READ(IFILE,103) (VECT(J),J=1,NLAM)
      WRITE(6,251) (VECT(J),J=1,NLAM)
C....OPTICAL CONSTITUENT SUMS AND CROSS PRODUCTS
      DO 4 J=1,NLAM
      XMU(J,NL)=XMU(J,NL)+VECT(J)
      DO 4 K=J,NLAM
    4 V(J,K)=V(J,K)+VECT(J)*VECT(K)
      IF(NVEC(NL).LE.1) GO TO 7
C....OPTICAL CONSTITUENT COVARIANCE MATRIX
      DO 5 I=1,NLAM
      DO 5 J=1,NLAM
      V(I,J)=(V(I,J)-(XMU(I,NL)*XMU(J,NL))/XVEC)/(XVEC-1.)
      IF(I.GT.J) V(I,J)=V(J,I)
    5 CONTINUE
C....OPTICAL CONSTITUENT MEAN VECTOR
      DO 6 I=1,NLAM
    6 XMU(I,NL)=XMU(I,NL)/XVEC
      IF(L.EQ.1) GO TO 7
      CALL MATSQR(V,C(1,1,NL),NLAM)
    7 IF(L.NE.1) GO TO 8
C....MEASURED CANOPY REFLECTANCE VECTOR FOR COMPARISON WITH MODEL RESULT
      CALL UTTL(XMU(1,NL),CANRM)
      DO 360 I=1,NLAM
      DO 360 J=1,NLAM
```

```
  340 COVM(I,J) = V(I,J)
    8 WRITE(6,204) (XMU(I,NL),I=1,NLAM)
      IF(NVEC(NL).LE.1) GO TO 11
      WRITE(6,205) (DATAID(I,NL),I=1,7)
      DO 10 I=1,NLAM
   10 WRITE(6,251) (V(I,J),J=1,NLAM)
      WRITE(6,211)
C....OPTICAL CONSTITUENT CORRELATION MATRIX
      DO 12 I=1,NLAM
      DO 9 J=1,NLAM
    9 COR(I,J)=V(I,J)/(SQRT(V(I,I))*SQRT(V(J,J)))
      WRITE(6,251) (COR(I,J),J=1,NLAM)
   12 CONTINUE
   11 CONTINUE
      WRITE (6,210)
C.....................                  BIG LOOP             .....................
      ISTOP=0
      DO 7000 ISAMP=1,NSAMP
      DO 6000 ITRIAL=1,NTRIAL
      CTIME=SECOND(ARG)
      IF((ITRIAL.GT.1).AND.(ISTOH.EQ.0)) GO TO 9050
C....GENERATE RANDOM DIRECT AND DIFFUSE IRRADIANCE VECTORS FROM THE
C....INPUT DISTRIBUTIONS ASSUMING THEY ARE MULTIVARIATE NORMAL.
      WRITE(6,292)
      DO 25 I=1,2
      CALL UTIL(XMU(1,I),AVEC)
      IF(NVEC(I).LE.1) GO TO 14
      CALL NRM(C(1,1,I),XMU(1,I),AVEC)
   14 WRITE(6,206) (DATAID(J,I),J=1,7),(AVEC(J),J=1,NLAM)
      GO TO (15,16),I
C....TOTAL SKY IRRADIANCE
   15 CALL UTIL(AVEC,SKYIM)
      GO TO 25
C....DIFFUSE IRRADIANCE
   16 CALL UTIL(AVEC,DIFIM)
   25 CONTINUE
C....COMPUTE PROPORTION OF IRRADIANCE WHICH IS DIRECT AND PROPORTION
C....WHICH IS DIFFUSE.
      DO 40 J=1,NLAM
      SOURCE(1,J)=(SKYIM(J)-DIFIM(J))/(SKYIM(J)*LZS)
      DO 40 I=1,NBANDS
   40 SOURCE(I+1,J)=DIFIM(J)*XK(I)/(SKYIM(J)*SIN(THETA(I+1)))
      WRITE(6,209)
      DO 45 I=1,NSOUR
   45 WRITE(6,203) (SOURCE(I,J),J=1,NLAM)
C....POPULATE FIRST (TOP) DOWN DWELL LAYER (DR) WITH INCIDENT DIRECT AND
C....DIFFUSE LIGHT.  DOWN DWELL RADIATION FLUX (DR) IS INDEXED FROM 1 TO
C....NLAY IN A DOWN GOING SEQUENCE.  UPWARD DWELL RADIATION FLUX (UR)
C....IS INDEXED FROM 1 TO NLAY+1 IN UPWARD GOING SEQUENCE.  THAT IS FOR
C....FOR UR, LAYER 1 IS THE LAYER IMMEDIATELY ABOVE THE BACKGROUND.  THE
C....FLUX IN LAYER NLAY+1 IS THAT WHICH ESCAPES THE CANOPY AND TOGETHER
C....WITH THE INCIDENT FLUX DETERMINES THE CANOPY REFLECTANCE.
 9050 CONTINUE
      CALL SETC(0.,REFER(1),REFER(17))
      CALL SETC(0.,DR(1,1,1),UR(4,10,17))
      CALL SETC(0,IGOD(1,1),IGOU(4,10))
      DO 1003 J=1,NSOUR
      DO 1003 K=1,NLAM
 1003 DR(1,J,K)=SOURCE(J,K)
```

```
C....SET FLUX LEVEL INDICATORS (DOWNWARD)
      CALL ETHRES(NLAY,NSOUR,-1)
C....TOTAL INCIDENT FLUX REFLECTED FROM A LAMBERTIAN SURFACE AND DE-
C....TECTED BY A VERTICAL SENSOR
      DO 1500 JSOR=1,NSOUR
      DO 1400 KL=1,NLAM
      REFER(KL)=REFER(KL)+SOURCE(JSOR,KL)*SIN(THETA(JSOR))*SINFOV*SINFOV
 1400 CONTINUE
 1500 CONTINUE
      WRITE(6,282) (REFER(KL),KL=1,NLAM)
C...........FAST LOOP TRACES LIGHT ATTENUATION THROUGH CANOPY...........
C....FLUX PASSING THROUGH LAYERS IN A DOWNWARD DIRECTION
 2000 CONTINUE
      DO 2600 IL=1,NLAY
      DO 2500 JSOR=1,NSOUR
C....CHECK FLUX LEVEL INDICATOR
      IF(IGOD(IL,JSOR).EQ.0.) GO TO 2500
C....DID LIGHT STRIKE LEAF
      CALL FGAP(IL,JSOR,-1,IHIT,MTYPE)
      IF(IHIT.EQ.0) GO TO 2200
      DO 2100 IPHIP=1,18
C....DIRECTION COSINES OF SOURCE SECTOR (LVLH)
      SXL = XS(JSOR,IPHIP)
      SYL = YS(JSOR,IPHIP)
      SZL = ZS(JSOR)
      CALL LAMBTN(IL,JSOR,MTYPE,-1,NSOUR)
 2100 CONTINUE
      GO TO 2400
C....GAP ENCOUNTERED IN DOWNWARD PATH
 2200 DO 2250 KL=1,NLAM
 2250 DR(IL+1,JSOR,KL)=DR(IL+1,JSOR,KL)+DR(IL,JSOR,KL)
 2400 CALL SETZ(IL,JSOR,-1)
 2500 CONTINUE
      CALL ETHRES(NLAY,NSOUR,-1)
 2600 CONTINUE
C....BACKGROUND REACHED - REFLECTS LAMBERTIAN
      CALL ETHRES(NLAY,NSOUR,-1)
      DO 3600 JSOR=1,NSOUR
      CALL UTIL(XMU(1,3),AVEC)
      IF(NVEC(3).LE.1) GO TO 3100
      CALL NRM(C(1,1,3),XMU(1,3),AVEC)
 3100 CALL UTIL(AVEC,RG)
      DO 3400 JJ=2,NSOUR
      IL = NLAY + 1
      DO 3400 KL=1,NLAM
 3400 UR(1,JJ,KL)=UR(1,JJ,KL)+RG(KL)*DR(IL,JSOR,KL)*ZS(JSOR)*XK(JJ-1)
      CALL SETZ(NLAY+1,JSOR,-1)
 3600 CONTINUE
      CALL ETHRES(NLAY,NSOUR,+1)
C....FLUX PASSING THROUGH LAYERS IN AN UPWARD DIRECTION
      DO 4600 IL=1,NLAY
      DO 4500 JSOR=2,NSOUR
C....CHECK FLUX LEVEL INDICATOR
      IF(IGOD(IL,JSOR).EQ.0) GO TO 4500
C....DID LIGHT STRIKE LEAF
      CALL FGAP(IL,JSOR,+1,IHIT,MTYPE)
      IF(IHIT.EQ.0) GO TO 4200
      DO 4100 IPHIP=1,18
C....DIRECTION COSINES OF SOURCE SECTOR (LVLH)
```

```
      SXL = XS(JSOR.IPHIP)
      SYL = YS(JSOR.IPHIP)
      SZL = ZS(JSOR)
      CALL LAMBTN(IL,JSOR.MTYPE.+1.NSOUR)
 4100 CONTINUE
      GO TO 4400
C....GAP ENCOUNTERED IN UPWARD PATH
 4200 DO 4250 KL=1.NLAM
 4250 UR(IL+1.JSOR,KL)=UR(IL+1,JSOR.KL)+UR(IL,JSOR,KL)
 4400 CALL SETZ(IL,JSOR.+1)
 4500 CONTINUE
      CALL ETHRES(NLAY.NSOUR,+1)
 4600 CONTINUE
      CALL ETHRES(NLAY.NSOUR,-1)
      CALL ETHRES(NLAY,NSOUR,+1)
C....RECYCLE THROUGH LAYERS UNTIL FLUX EXHAUSTED
      DO 5000 IL=1.NLAY
      DO 5000 JSOR=2,NSOUR
      IF (IGOU(IL,JSOR).NE.0) GO TO 2000
 5000 CONTINUE
      DO 5001 IL=2.NLAYP1
      DO 5001 JSOR=1.NSOUR
      IF(IGOD(IL.JSOR).NE.0) GO TO 2000
 5001 CONTINUE
C....FLUX EXHAUSTED IN ALL SOURCES--COMPUTE REFLECTANCE FOR THIS TRIAL
      DO 5200 JSOR=2,NSOUR
      DO 5200 KL=1.NLAM
      RIT(JSOR,KL)=UR(NLAY+1.JSOR.KL)*DM1(JSOR)/REFER(KL)
 5200 RITBAR(JSOR.KL)=RITBAR(JSOR.KL)+RIT(JSOR,KL)
      DTIME=SECOND(ARG)-CTIME
      WRITE(6.283) ISAMP,ITRIAL,DTIME
      DO 5300 JSOR=2,NSOUR
      ZDEG=105-10*JSOR
 5300 WRITE(6.284) ZDEG.(RIT(JSOR.KL).KL=1,NLAM)
      IF(TIMLFT(ARG).LT.DTIME*2.) GO TO 6100
 6000 CONTINUE
C....TRIALS COMPLETE FOR THIS SAMPLE POINT
      FTRIAL=NTRIAL
      GO TO 6200
 6100 FTRIAL=ITRIAL
      WRITE(6.285) ISAMP,ITRIAL
 6200 DO 6300 JSOR=2,NSOUR
      DO 6300 KL=1.NLAM
 6300 RITBAR(JSOR.KL)=RITBAR(JSOR.KL)/FTRIAL
      WRITE(6.286) ISAMP
      DO 6400 JSOR=2,NSOUR
      ZDEG=105-10*JSOR
 6400 WRITE(6.284) ZDEG.(RITBAR(JSOR.KL),KL=1.NLAM)
      DO 6600 JSOR=2,NSOUR
      DO 6500 KL=1.NLAM
      RBAR(JSOR.KL)=RBAR(JSOR.KL)+RITBAR(JSOR.KL)
      DO 6500 KLL=1.NLAM
 6500 COV(JSOR.KL.KLL)=COV(JSOR.KL.KLL)+RITBAR(JSOR,KL)*RITBAR(JSOR,KLL)
      DO 6600 KL=1.NLAM
 6600 RITBAR(JSOR.KL)=0.
      IF(ISTOP.EQ.1) GO TO 7100
 7000 CONTINUE
      FSAMP=NSAMP
      GO TO 7150
```

```
 7100 FSAMP=ISAMP
C....ALL SAMPLE POINTS ESTIMATED
 7150 DO 7200 JSOR=2,NSOUR
      DO 7200 KL=1,NLAM
 7200 RBAR(JSOR,KL)=RBAR(JSOR,KL)/FSAMP
      DO 7900 JSOR=2,NSOUR
      ZDEG=105-10*JSOR
      IF(FSAMP.LE.1.) GO TO 7600
      DO 7400 I=1,NLAM
      DO 7300 J=1,NLAM
 7300 COV(JSOR,I,J)=(COV(JSOR,I,J)-FSAMP*RBAR(JSOR,I)*RBAR(JSOR,J))
     1/(FSAMP-1.)
 7400 SIG(I)=SQRT(COV(JSOR,I,I))
      DO 7500 I=1,NLAM
      DO 7500 J=1,NLAM
 7500 COR(I,J)=COV(JSOR,I,J)/(SIG(I)*SIG(J))
 7600 WRITE(6,287) ZDEG,(RBAR(JSOR,KL),KL=1,NLAM)
      IF(FSAMP.LE.1.) GO TO 7900
      WRITE(6,288)
      DO 7700 I=1,NLAM
 7700 WRITE(6,289) (COV(JSOR,I,J),J=1,NLAM)
      WRITE(6,291)
      DO 7800 I=1,NLAM
 7800 WRITE(6,289) (COR(I,J),J=1,NLAM)
 7900 CONTINUE
      IF(IFILE.EQ.5) GO TO 8000
      STOP
C..............................DATA FORMATS.............................
  100 FORMAT(8A10,/,4X,I3,7X,I4,7X,2I2,6X,F6.2,7X,F7.2,5X,F7.2,8X,I2,/,
     15X,I2,7X,I1,7X,I5,9X,I5,8X,I5)
  101 FORMAT(8F10.5)
  102 FORMAT(I10,7A10)
  103 FORMAT(8E10.4)
  200 FORMAT(*1*,43X,*SOLAR RADIATION/VEGETATION CANOPY REFLECTANCE MODE
     1L*,//,64X,*INPUT DATA*,//,1X,8A10,/,
     2* JULIAN DAY *,I3,*, YEAR *,I4,*, TIME *,2I2,* HOURS*,/,
     3* LATITUDE = *,F6.2,* DEGREES, LONGITUDE = *,F7.2,* DEGREES*,/,
     4* SOLAR DECLINATION = *,F6.2,* DEGREES*,/,
     5* BAND WIDTH OF DIFFUSE VECTORS = *,F5.1,* DEGREES*,/,
     6* NUMBER OF WAVELENGTH BANDS SIMULATED *,I2,/,
     7* NUMBER OF CANOPY CONSTITUENTS *,I1,/,
     8* K DIGIT ODD NO. TO INITIALIZE RANDOM SEQUENCE = *,I5,/,
     9* NSAMP =*,I5,/,
     A* NTRIAL = *,I5,/,
     B* NLAY = *,I1,
     C)
  201 FORMAT(*0WAVELENGTHS SIMULATED*,/,*0*,F7.4,16F8.4)
  202 FORMAT(*0....*,3A10,*NUMBER OF VECTORS = *,I2)
  203 FORMAT(* *,F7.4,16F8.4)
  204 FORMAT(*0      MEAN*,/,8X,10F12.4)
  205 FORMAT(*0      COVARIANCE MATRIX*)
  206 FORMAT(*0RANDOM VECTOR GENERATED FROM THE *,7A10,/,(* *,10E12.4))
  207 FORMAT(*0LAI = *,F4.2,4X,*S = *,F4.2)
  208 FORMAT(*0DIFFUSE VECTOR COEFFICIENTS*,/,
     19(*      K   *),/,(9F8.4))
  209 FORMAT(*0IRRADIANCE SOURCE VECTORS*)
  210 FORMAT(1H1)
  211 FORMAT(*0      CORRELATION MATRIX*)
  212 FORMAT(*0DM1 = *,9F8.4)
```

```
 7100 FSAMP=ISAMP
C....ALL SAMPLE POINTS ESTIMATED
 7150 DO 7200 JSOR=2,NSOUR
      DO 7200 KL=1,NLAM
 7200 RBAR(JSOR,KL)=RBAR(JSOR,KL)/FSAMP
      DO 7900 JSOR=2,NSOUR
      ZDEG=105-10*JSOR
      IF(FSAMP.LE.1.) GO TO 7600
      DO 7400 I=1,NLAM
      DO 7300 J=1,NLAM
 7300 COV(JSOR,I,J)=(COV(JSOR,I,J)-FSAMP*RBAR(JSOR,I)*RBAR(JSOR,J))
     1/(FSAMP-1.)
 7400 SIG(I)=SQRT(COV(JSOR,I,I))
      DO 7500 I=1,NLAM
      DO 7500 J=1,NLAM
 7500 COR(I,J)=COV(JSOR,I,J)/(SIG(I)*SIG(J))
 7600 WRITE(6,287) ZDEG,(RBAR(JSOR,KL),KL=1,NLAM)
      IF(FSAMP.LE.1.) GO TO 7900
      WRITE(6,288)
      DO 7700 I=1,NLAM
 7700 WRITE(6,289) (COV(JSOR,I,J),J=1,NLAM)
      WRITE(6,291)
      DO 7800 I=1,NLAM
 7800 WRITE(6,289) (COR(I,J),J=1,NLAM)
 7900 CONTINUE
      IF(IFILE.EQ.5) GO TO 8000
      STOP
C.........................DATA FORMATS..............................
  100 FORMAT(8A10,/,4X,I3,7X,I4,7X,2I2,6X,F6.2,7X,F7.2,5X,F7.2,8X,I2,/,
     15X,I2,7X,I1,7X,I5,9X,I5,8X,I5)
  101 FORMAT(8F10.5)
  102 FORMAT(I10,7A10)
  103 FORMAT(8E10.4)
  200 FORMAT(*1*,43X,*SOLAR RADIATION/VEGETATION CANOPY REFLECTANCE MODE
     1L*,//,64X,*INPUT DATA*,//,1X,8A10,/,
     2* JULIAN DAY *,I3,*, YEAR *,I4,*, TIME *,2I2,* HOURS*,/,
     3* LATITUDE = *,F6.2,* DEGREES, LONGITUDE = *,F7.2,* DEGREES*,/,
     4* SOLAR DECLINATION = *,F6.2,* DEGREES*,/,
     5* BAND WIDTH OF DIFFUSE VECTORS = *,F5.1,* DEGREES*,/,
     6* NUMBER OF WAVELENGTH BANDS SIMULATED *,I2,/,
     7* NUMBER OF CANOPY CONSTITUENTS *,I1,/,
     8* K DIGIT ODD NO. TO INITIALIZE RANDOM SEQUENCE = *,I5,/,
     9* NSAMP =*,I5,/,
     A* NTRIAL = *,I5,/,
     B* NLAY = *,I1,
     C)
  201 FORMAT(*0WAVELENGTHS SIMULATED*,/,*0*,F7.4,16F8.4)
  202 FORMAT(*0....*,3A10,*NUMBER OF VECTORS = *,I2)
  203 FORMAT(* *,F7.4,16F8.4)
  204 FORMAT(*0         MEAN*,/,8X,10F12.4)
  205 FORMAT(*0         COVARIANCE MATRIX*)
  206 FORMAT(*0RANDOM VECTOR GENERATED FROM THE *,7A10,/,(* *,10E12.4))
  207 FORMAT(*0LAI = *,F4.2,4X,*S = *,F4.2)
  208 FORMAT(*0DIFFUSE VECTOR COEFFICIENTS*,/,
     19(*       K   *),/,(9F8.4))
  209 FORMAT(*0IRRADIANCE SOURCE VECTORS*)
  210 FORMAT(1H1)
  211 FORMAT(*0         CORRELATION MATRIX*)
  212 FORMAT(*0DM1 = *,9F8.4)
```

```
221 FORMAT(*0THRESD = *,10F8.4/* THRESU = *,10F8.4)
222 FORMAT(*0DIRECTION COSINES OF SUN        *,3F8.4)
223 FORMAT(*0THETA =*,10F8.4)
227 FORMAT(///* *,25(1H.),2X,*CANOPY GEOMETRY*,2X,25(1H.)//)
228 FORMAT(/* *,25(1H.))
230 FORMAT(*0LEAF ANGLE COMPUTATIONS  -  IL = *,I1,
   1*  IMAT = *,I1,*  NANG = *,I2,/,* XLFA,YLFA*,
   1/,(2X,16F8.3))
231 FORMAT(*0NANGLE(IL,IMAT) = *,I2)
232 FORMAT(*0     FLA =*,10F8.3)
233 FORMAT(*0     F   =*,10F8.3)
235 FORMAT(*0     OP  =*,9F8.3,3X,*OPM = *,F8.3,3X,*PHIT = *,F8.3)
251 FORMAT(8X,10E12.4)
282 FORMAT(*0REFFER = *,8E13.4)
283 FORMAT(*0REFLECTANCE FOR SAMPLE*,I3,* TRIAL*,I3,5X,
   1*COMPUTATION TIME WAS*,F5.1,* SECONDS.*)
284 FORMAT(* Z =*,I3,* DEG*,3X,10F7.3)
285 FORMAT(*0CAUTION....SAMPLE*,I3,* CONTAINS ONLY*,I3,* TRIALS.*)
286 FORMAT(*0*,75(1H.)/* MEAN REFLECTANCE FOR SAMPLE*,I3)
287 FORMAT(*0GRAND MEAN FOR Z =*,I3,* DEGREES.*,3X,10F7.3)
288 FORMAT(*0   COVARIANCE MATRIX*)
289 FORMAT(7X,10E12.8)
291 FORMAT(*0   CORRELATION MATRIX*)
292 FORMAT(1X,120(1H-))
    END
```

```
      SUBROUTINE LAMBTN(IL,JSOR,MTYPE,IDIR,NSOUR)
C.....FOR A GIVEN FLUX SOURCE THIS PROGRAM CALLS THE APPROPRIATE
C.....PROGRAMS TO DETERMINE LEAF ORIENTATION AND OPTICAL PROPERTIES
C.....AND UPDATES THE DIFFUSE SOURCES WITH SCATTERED FLUX.
C     SXL, SYL, SZL
C     JSOR
C     LXS, LYS, LZS
C     IDIR
C     NLAM
C     DR(I,J,K)
C     UR(I,J,K)
C     MTYPE
C     IL
C     NSOUR
C     XMAT1R, XMAT1T
C     XMAT2R, XMAT2T
C     XMAT3R, XMAT3T
C     ZENITH
C   OUTPUT VARIABLES
C     DR(I,J,K)
C     UR(I,J,K)
C
      COMMON DUM0(17),XK(9),SXL,SYL,SZL,XLF,YLF,ZLF
      COMMON/C1/DUM1(7),NLAM,DUM2(26),CE1PI,DUM3(24),LXS,LYS,LZS
      COMMON/C2/DUM4(51),XMAT1R(17),XMAT1T(17),XMAT2R(17),XMAT2T(17),
     1XMAT3R(17),XMAT3T(17),DUM5(214),ZENITH(10)
      COMMON/C6/DR(4,10,17),UR(4,10,17)
      COMMON/CMAT/MTP(3),NLAY,OPM(10)
      DIMENSION H(17),R(17),T(17),PTRP(2,17)
      REAL LXS,LYS,LZS
      DATA PIO2/1.570796327/
C.....SET DIRECTION COSINES OF SOURCE
      XL=SXL
      YL=SYL
      ZL=SZL
      IF(JSOR.NE.1) GO TO 100
      XL=LXS
      YL=LYS
      ZL=LZS
C.....RANDOM LEAF ORIENTATION, DIRECTION COSINES OF NORMAL, AND
C.....LEAF OPTICAL PROPERTIES
  100 IF(IDIR.EQ.-1) IXL=IL
      IF(IDIR.EQ.1) IXL=NLAY-IL+1
      CALL LANGLE(IXL,MTYPE,THETAL,PHIL)
C.....SET SIDE OF LEAF WHICH LIGHT STRIKES. ISIDE=1 (TOP), -1 (BOTTOM).
      ISIDE=-IDIR
      DOT=XL*XLF+YL*YLF+ZL*ZLF
      IF(DOT.LT.0.) ISIDE=IDIR
      COSLS=ABS(DOT)
      IF(IDIR.EQ.1) GO TO 5
      DO 4 KL=1,NLAM
    4 H(KL)=DR(IL,JSOR,KL)*COS(ZENITH(JSOR)-THETAL)/18.
      GO TO 9
    5 DO 7 KL=1,NLAM
    7 H(KL)=UR(IL,JSOR,KL)*COS(ZENITH(JSOR)-THETAL)/18.
    9 CONTINUE
C.....SET OPTICAL PROPERTIES FOR LEAF TYPE
      GO TO (10,20,30),MTYPE
   10 DO 15 KL=1,NLAM
```

```
      R(KL)=XMAT1R(KL)
   15 T(KL)=XMAT1T(KL)
      GO TO 40
   20 DO 25 KL=1,NLAM
      R(KL)=XMAT2R(KL)
   25 T(KL)=XMAT2T(KL)
      GO TO 40
   30 DO 35 KL=1,NLAM
      R(KL)=XMAT3R(KL)
   35 T(KL)=XMAT3T(KL)
   40 CONTINUE
C....UPDATE DIFFUSE SOURCES WITH SCATTERED RADIATION FLUX
      DO 50 JJSOR=2,NSOUR
      IF(ISIDF.EQ.-1) CALL BFLUX(THETAL,ZENITH(JJSOR),H,T,R,NLAM,PTRP)
      IF(ISIDF.EQ.1) CALL BFLUX(THETAL,ZENITH(JJSOR),H,R,T,NLAM,PTRP)
      DO 50 KL=1,NLAM
      IF(IDIR.EQ.1) GO TO 45
      DR(IL+1,JJSOR,KL)=DR(IL+1,JJSOR,KL)+PTRP(2,KL)
      UR(NLAY+2-IL,JJSOR,KL)=UR(NLAY+2-IL,JJSOR,KL)+PTRP(1,KL)
      GO TO 50
   45 DR(NLAY+2-IL,JJSOR,KL)=DR(NLAY+2-IL,JJSOR,KL)+PTRP(2,KL)
      UR(IL+1,JJSOR,KL)=UR(IL+1,JJSOR,KL)+PTRP(1,KL)
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RFLUX(TA,TRP,H,R,T,NLAM,PTRP)
C.....GIVEN THE IRRADIANCE H OF A LEAF INCLINED AT TA THIS PROGRAM
C.....DETERMINES THE FLUX REFLECTED AND TRANSMITTED INTO A SOURCE
C.....BAND WHOSE ZENITH ANGLE IS TRP.
      DIMENSION PTRP(2,17),H(17),R(17),T(17)
      DATA PI/3.141592654/,PIO2/1.570796327/
      F1(X,Y)=COS(TA)*(SIN(X)**2-SIN(Y)**2)
      F2(X)=ACOS(-1/(TAN(TA)*TAN(X)))
      F3(X,Y,Z)=2.*SIN(TA)*SIN(X)*(DEL+.25*(SIN(2.*Y)-SIN(2.*Z)))/PI
      DEL=.087266463
      T1=TRP-DEL
      T2=TRP+DEL
      IF(TA.LE.PIO2-T2) GO TO 10
      IF(TA.GE.PIO2-T1) GO TO 20
      GO TO 30
C....CASE 1
   10 XF1=F1(T2,T1)
      DO 15 KL=1,NLAM
      PTRP(1,KL)=R(KL)*H(KL)*XF1
      PTRP(2,KL)=T(KL)*H(KL)*XF1
   15 CONTINUE
      RETURN
C....CASE 2
   20 XF1=F1(T2,T1)
      IF(TA.LE.1.5533) GO TO 21
      PRP=PIO2
      GO TO 22
   21 PRP=F2(TRP)
   22 XF3=F3(PRP,T1,T2)
      DO 25 KL=1,NLAM
      PTRP(1,KL)=H(KL)*(R(KL)+T(KL))*XF3+
     1(R(KL)*H(KL)*PRP-T(KL)*H(KL)*PI+T(KL)*H(KL)*PRP)*XF1/PI
      PTRP(2,KL)=H(KL)*(T(KL)+R(KL))*XF3+
     1(T(KL)*H(KL)*PRP-R(KL)*H(KL)*PI+R(KL)*H(KL)*PRP)*XF1/PI
   25 CONTINUE
      RETURN
C....CASE 3
   30 TB=PIO2-TA
      XF1=F1(TB,T1)
      DO 35 KL=1,NLAM
      PTRP(1,KL)=R(KL)*H(KL)*XF1
   35 PTRP(2,KL)=T(KL)*H(KL)*XF1
      IF(TB+T2.LE.3.106) GO TO 36
      PRP=PIO2
      GO TO 37
   36 PRP=F2((TB+T2)/2.)
   37 XF1=F1(T2,TB)
      DEL=((TRP+TA)/2.)-.74176493
      XF3=F3(PRP,TB,T2)
      DO 40 KL=1,NLAM
      PTRP(1,KL)=PTRP(1,KL)+H(KL)*(R(KL)+T(KL))*XF3+
     1(R(KL)*H(KL)*PRP-T(KL)*H(KL)*PI+T(KL)*H(KL)*PRP)*XF1/PI
      PTRP(2,KL)=PTRP(2,KL)+H(KL)*(T(KL)+R(KL))*XF3+
     1(T(KL)*H(KL)*PRP-R(KL)*H(KL)*PI+R(KL)*H(KL)*PRP)*XF1/PI
   40 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LANGLE(IL,MTYPE,THETAL,PHIL)
C----THIS PROGRAM SELECTS A RANDOM LEAF INCLINATION (THETAL) AND AZIMUTH
C     (PHIL) AND THEN COMPUTES ITS DIRECTION COSINES XLF, YLF, AND ZLF.
C     THE INTERMEDIATE PARAMETERS SINL, COSL, SINP, AND COSP ARE ALSO
C     OUTPUT.  RANDOM LEAF REFLECTANCE AND TRANSMITTANCE VECTORS ARE ALSO
C     SELECTED.
C
C     INPUT
C       IL
C       MTYPE
C       NANGLE
C     OUTPUT
C       THETAL
C       PHIL
C       XLF, YLF, ZLF
C       SINL, COSL, SINP, COSP
C       XMAT1R, XMAT1T, XMAT2R, XMAT2T, XMAT3R, XMAT3T
C
      COMMON/C1/DUM2(31),CERTD,DUM7(3),CE2PI
      COMMON/C4/NANGLE(3,3),FLA(3,3,10),SLAI(3,3),FLAI(3,3),PHIT(3,3,10)
      COMMON/C8/SINL,COSL,SINP,COSP
      COMMON DUM3(29),XLF,YLF,ZLF
C----DETERMINE RANDOM LEAF ORIENTATION.
      FM=NANGLE(IL,MTYPE)
      XT=RANF(0.)
      XI=1.+(FM-1.)*XT
      IX=XI
      IF(IX.EQ.NANGLE(IL,MTYPE)) IX=IX-1
      IXP1=IX+1
      THETAL=FLA(IL,MTYPE,IX)+.5*(FLA(IL,MTYPE,IXP1)-FLA(IL,MTYPE,IX))
      PHIL=CE2PI*RANF(0.)
C----THETAL, PHIL ARE LEAF INCLINATION AND AZIMUTH, RESPECTIVELY.
1     CONTINUE
      SINL=SIN(THETAL)
      COSL=COS(THETAL)
      SINP=SIN(PHIL)
      COSP=COS(PHIL)
C----COMPUTE LEAF NORMAL DIRECTION COSINES
      XLF=-SINL*COSP
      YLF=-SINL*SINP
      ZLF=COSL
C----SELECT RANDOM LEAF REFLECTANCE AND TRANSMITTANCE VECTORS.
      CALL OPTICAL(MTYPE)
      RETURN
      END
```

```
      SUBROUTINE COP(ALPHA,BETA,OP)
C
C....THIS PROGRAM CALCULATES THE MEAN PROJECTION OF A UNIT LEAF AREA IN
C....THE DIRECTION OF THE SOURCE.  THE LEAF IS INCLINED AT AN ANGLE
C....ALPHA AND IS ASSUMED TO BE AZIMUTHALLY ISOTROPIC.  THE SOURCE
C....DIRECTION IS AT AN AZIMUTH OF ZERO AND AN INCLINATION OF BETA.
C
      COMMON/C1/DUM1(33),CEPIO2
      OP=COS(ALPHA)*SIN(BETA)
      IF(ALPHA.LE.BETA) RETURN
C....THETA0 IS THE LEAF AZIMUTH ANGLE AT WHICH OP BECOMES NEGATIVE AND
C....IS IN THE FIRST QUADRANT.  THE FUNCTION OP IS SYMMETRIC AND HENCE
C....IS AVERAGED OVER LEAF AZIMUTH ANGLES OF 0 TO PI RADIANS.
      THETA0=ACOS(TAN(BETA)/TAN(ALPHA))
      TANT0=TAN(THETA0)
      OP=OP*(1.+(TANT0-THETA0)/CEPIO2)
      RETURN
      END
```

```
      SUBROUTINE COPM(G,OP,OPM)
C....THIS PROGRAM CALCULATES THE MEAN PROJECTION OF A UNIT LEAF AREA IN
C....THE DIRECTION OF THE SOURCE (OPM) FOR THE SIMULATED CANOPY.  THE
C....LEAVES OF THE CANOPY ARE ASSUMED TO BE AZIMUTHALLY ISOTROPIC.  THE
C....OP FUNCTION USED IN THE CALCULATION HAS BEEN PREVIOUSLY DETERMINED
C....FOR A GIVEN SOURCE DIRECTION FOR LEAF INCLINATION ANGLES OF
C....5, 15, ...., 85 DEGREES.  G IS THE LEAF INCLINATION ANGLE DENSITY
C....FUNCTION.
C
      DIMENSION OP(9),G(9)
      OPM=0.
      DO 1 I=1,9
    1 OPM=OPM+OP(I)*G(I)
      RETURN
      END
```

```
      SUBROUTINE PDENS(IL,MTYPE,IANGLE,OPM)
C----THIS PROGRAM COMPUTES THE PROBABILITY THAT LIGHT AT INCIDENT ANGLE
C    THETA(IANGLE) INTERACTS WITH MATERIAL TYPE MTYPE WITHIN CANOPY
C    LAYER IL.
C
C    INPUT
C      IL
C      MTYPE
C      IANGLE
C      OPM
C      SLAI
C      FLAI
C      THETA
C    OUTPUT
C      PHIT
C
      COMMON/C2/DUM(357),THETA(10)
      COMMON/C4/NANGLE(3,3),FLA(3,3,10),SLAI(3,3),FLAI(3,3),PHIT(3,3,10)
      ARG=1.-(SLAI(IL,MTYPE)*OPM/SIN(THETA(IANGLE)))
      IF (ARG.LE.0.) GO TO 1
      P0=ARG**(FLAI(IL,MTYPE)/SLAI(IL,MTYPE))
      GO TO 2
1     P0 = 0.
      WRITE(6,100) IANGLE
100   FORMAT (1H0, *   P0 SET TO ZERO*,I5)
2     CONTINUE
      PHIT(IL,MTYPE,IANGLE)=1.-P0
      RETURN
      END
```

```
      SUBROUTINE PGAP(IL,IANGLE,IDIR,IHIT,MTYPE)
C----THIS PROGRAM DETERMINES IF AN INTERACTION IS BEING MADE IN LAYER IL
C    AND SETS THE MATERIAL TYPE OF LAYER IL.
C
C    INPUT
C      IL
C      IANGLE
C      IDIR
C      NLAY
C      MTP
C      PHIT
C    OUTPUT
C      IHIT
C      MTYPE
C
      COMMON/C4/NANGLE(3,3),FLA(3,3,10),SLAI(3,3),FLAI(3,3),PHIT(3,3,10)
      COMMON/CMAT/MTP(3),NLAY
      IF(IDIR.LT.0) GO TO 10
      ILAYER=NLAY+1-IL
      GO TO 20
   10 ILAYER=IL
   20 MTYPE=MTP(ILAYER)
      IHIT=0
      TEST=RANF(0.)
      IF(PHIT(ILAYER,MTYPE,IANGLE).LT.TEST) GO TO 30
      IHIT=1
   30 RETURN
      END
```

```
      SUBROUTINE ETHRES(NLAY,NSOUR,IDIR)
C----THIS PROGRAM DETERMINES (FOR EACH LAYER AND FOR ALL LIGHT SOURCE
C     DIRECTIONS) IF THE SOURCE FLUX IS ABOVE THRESHOLD REQUIREMENTS IN
C     THE DIRECTION INDICATED BY IDIR.  INDICATORS IGOD OR IGOU ARE SET
C     ACCORDINGLY.
C
C     INPUT
C       NLAY
C       NSOUR
C       IDIR
C       NLAM
C       DR
C       UR
C       THRES
C     OUTPUT
C       IGOD
C       IGOU
C
      COMMON/C1/DUMO(7),NLAM
      COMMON/C6/DR(4,10,17),UR(4,10,17),THRESD(10),IGOD(4,10),IGOU(4,10)
     1,THRESU(10)
C----DOWNWARD FLUX
      IF(IDIR.GT.0) GO TO 10
      NLAYER=NLAY+1
      DO 2 I=1,NLAYER
      DO 2 J=1,NSOUR
      IGOD(I,J)=0
      DO 1 K=1,NLAM
      IF(DR(I,J,K).LT.THRESD(J)) GO TO 1
      IGOD(I,J)=1
      GO TO 2
    1 CONTINUE
    2 CONTINUE
      RETURN
C----UPWARD FLUX
 10   CONTINUE
      DO 4 I=1,NLAY
      DO 4 J=2,NSOUR
      IGOU(I,J)=0
      DO 3 K=1,NLAM
      IF(UR(I,J,K).LT.THRESU(J)) GO TO 3
      IGOU(I,J)=1
      GO TO 4
    3 CONTINUE
    4 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SETZ(IL,IANGLE,IDIR)
C----THIS PROGRAM SETS THE FLUX (AND ITS APPROPRIATE INDICATORS) IN THE
C    IDIR DIRECTION AT ANGLE THETA(IANGLE) IN LAYER IL TO ZERO.
C
C    INPUT
C      IL
C      IANGLE
C      IDIR
C      NLAM
C    OUTPUT
C      DR
C      UR
C      IGOD
C      IGOU
C
      COMMON/C1/DUM1(7),NLAM
      COMMON/C6/DR(4,10,17),UR(4,10,17),THRES(10),IGOD(4,10),IGOU(4,10)
      IF(IDIR.EQ.1) GO TO 10
C----DOWNWARD FLUX
      DO 1 K=1,NLAM
    1 DR(IL,IANGLE,K)=0.
      IGOD(IL,IANGLE)=0
      RETURN
C----UPWARD FLUX
10    CONTINUE
      DO 2 K=1,NLAM
    2 UR(IL,IANGLE,K)=0.
      IGOU(IL,IANGLE)=0
      RETURN
      END
```

```
      SUBROUTINE OPTICAL(MTYPE)
C----THIS PROGRAM SELECTS RANDOM LEAF REFLECTANCE AND TRANSMITTANCE
C     VECTORS FOR MATERIAL TYPE MTYPE.
C
C     INPUT
C       MTYPE
C       NVEC
C       C
C       XMU
C     OUTPUT
C       XMAT1R, XMAT1T, XMAT2R, XMAT2T, XMAT3R, XMAT3T
C
      COMMON/L1/DATAID(7,9),XMU(17,9),C(17,17,9),NVEC(9)
      COMMON/C2/CANRM(17),SKYIM(17),DIFIM(17),XMAT1R(17)
     1,XMAT1T(17),XMAT2R(17),XMAT2T(17),XMAT3R(17),XMAT3T(17),RG(17),
     2XLAM(17),SOURCE(10,17),THETA(10)
      I=2*MTYPE+2
      J=I+1
      GO TO (10,20,30),MTYPE
C----SELECT MATERIAL TYPE 1 VECTORS
10    CONTINUE
      IF(NVEC(I).LE.1) GO TO 11
      CALL NRM(C(1,1,I),XMU(1,I),XMAT1R)
      GO TO 12
11    CALL UTIL(XMU(1,I),XMAT1R)
12    IF(NVEC(J).LE.1) GO TO 13
      CALL NRM(C(1,1,J),XMU(1,J),XMAT1T)
      RETURN
13    CALL UTIL(XMU(1,J),XMAT1T)
      RETURN
C----SELECT MATERIAL TYPE 2 VECTORS
20    CONTINUE
      IF(NVEC(I) .LE.1) GO TO 21
      CALL NRM(C(1,1,I),XMU(1,I),XMAT2R)
      GO TO 22
21    CALL UTIL(XMU(1,I),XMAT2R)
22    IF(NVEC(J).LE.1) GO TO 23
      CALL NRM(C(1,1,J),XMU(1,J),XMAT2T)
      RETURN
23    CALL UTIL(XMU(1,J),XMAT2T)
      RETURN
C----SELECT MATERIAL TYPE 3 VECTORS
30    CONTINUE
      IF(NVEC(I).LE.1) GO TO 31
      CALL NRM(C(1,1,I),XMU(1,I),XMAT3R)
      GO TO 32
31    CALL UTIL(XMU(1,I),XMAT3R)
32    IF(NVEC(J).LE.1) GO TO 33
      CALL NRM(C(1,1,J),XMU(1,J),XMAT3T)
      RETURN
33    CALL UTIL(XMU(1,J),XMAT3T)
      RETURN
      END
```

```
      SUBROUTINE NRM(C,Z,X)
C.....THIS PROGRAM GENERATES RANDOM SAMPLES FROM A GIVEN MULTIVARIANGE
C.....NORMAL DISTRIBUTION
      COMMON/C1/DUM(7),NLAM
      DIMENSION X(17),Y(17)
      DIMENSION C(17,17),Z(17)
      DO 10 I=1,NLAM
      Y(I)=GAUSS(0.,1.)
10    CONTINUE
      CALL VMULT(Y,C,X,NLAM)
      CALL VADD(X,Z,X,NLAM)
      RETURN
      END
```

```
      SUBROUTINE MATSQR(V,C,N)
      DIMENSION V(17,17),C(17,17)
      DO 30 J=1,N
      DO 30 I=1,N
      C(I,J)=0.
      IF(I.LT.J) GO TO 25
      IF(J.NE.1) GO TO 5
      C(I,J)=V(I,J)/SQRT(V(1,1))
      GO TO 30
    5 IF(I.NE.J) GO TO 15
      SUM2=0.
      IK=I-1
      K=1
   10 SUM2=SUM2+C(I,K)*C(I,K)
      K=K+1
      IF(K.LE.IK) GO TO 10
      IF(V(I,J)-SUM2.GE.0.) GO TO 11
      DIF=V(I,J)-SUM2
      WRITE(6,201) I,J,V(I,J),SUM2,DIF
  201 FORMAT(*0*,2I10,3F14.8)
      C(I,J)=0.
      GO TO 30
   11 CONTINUE
      C(I,J)=SQRT(V(I,J) SUM2)
      GO TO 30
   15 SUMPRO=0.
      IJ=J-1
      K=1
   20 SUMPRO=SUMPRO+C(I,K)*C(J,K)
      K=K+1
      IF(K.LE.IJ) GO TO 20
      C(I,J)=(V(I,J)-SUMPRO)/C(J,J)
      GO TO 30
   25 C(I,J)=0
   30 CONTINUE
      RETURN
      END
```

```
BLOCK DATA
COMMON/C1/DUM(30),CEDTR,CERTD,CEMTR,CEPIO2,CE1PI,CE2PI
DATA CEDTR,CERTD,CEMTR/.01745329 3,57.2957795,.00029088821/
DATA CEPIO2,CE1PI,CE2PI/1.57079632,3.14159265,6.28318530/
END
```

```
      SUBROUTINE TBLR(M, X, Y, XX, Z)
C
C....THIS PROGRAM FINDS THE INTEGRAL Z(X) OF THE FUNCTION Y(X) FROM X(1)
C....TO X(2M-1) USING SIMPSONS RULE.  THE INTEGRAL Z(X) IS NORMALIZED TO
C....1.0 AT X(2M-1).  THE TABLE OF Z VERSUS X IS THEN INVERTED TO DETER-
C....MINE X AS A FUNCTION OF Z AT M REGULARLY SPACED POINTS ALONG Z.
C
C     INPUT VARIABLES
C       M  = DESIRED NUMBER OF REGULARLY SPACED POINTS ALONG Z
C       X  = SPECIFIED AT 2M-1 POINTS
C       Y  = SPECIFIED AT 2M-1 POINTS
C     OUTPUT VARIABLES
C       XX = THE TABLE OF X VALUES FOR M REGULARLY SPACED POINTS
C             (M-1 INTERVALS) ALONG Z.
C       Z  = THE NORMALIZED INTEGRAL OF Y AT X(1), X(3), ...., X(2M-1).
C
      DIMENSION X(19),Y(19),Z(10),XI(10),XX(10)
C....SIMPSONS RULE INTEGRATION
10    Z(1) = 0.0
      DX = X(2) - X(1)
20    DO 50 J = 2,M
      J0 = 2*J - 3
30    J1 = 2*J - 2
      J2 = 2*J - 1
40    Z(J) = Z(J - 1) + DX*(Y(J0) +4.*Y(J1) + Y(J2))/3.0
50    XI(J) = X(J2)
      XI(1)=X(1)
C....NORMALIZE INTEGRAL Z(X)
60    DO 70 J = 1,M
70    Z(J) = Z(J)/Z(M)
C....FIND X AT M REGULARLY SPACED POINTS ALONG Z.
      XX(1) = X(1)
      EM = M - 1
      F = 1.0/EM
      JS=2
80    DO 120 K = 2,M
      ZT = K - 1
      ZT = ZT*F
90    DO 110 J =JS,M
      IF(Z(J) - ZT) 110, 100, 100
100   G = (ZT - Z(J - 1))    /(Z(J) - Z(J - 1))
      XX(K) = XI(J - 1) + G*(XI(J) - XI(J - 1))
      GO TO 115
110   CONTINUE
115   JS=J
120   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SUN
C----THIS PROGRAM CALCULATES THE POSITION OF THE SUN
C
C     INPUT
C       TIME
C       GLAT
C       DEC
C     OUTPUT
C       SINLAT, COSLAT
C       SINDEC. COSDEC
C       COSH
C       SINZ, COSZ
C       SINAZ, COSAZ
C       LXS, LYS, LZS
C
C          TIME OF SIMULATION (HOURS)
C          GLAT IS SITE GEOGRAPHICAL LATITUDE
C          GLONG IS SITE LONGITUDE
C          DEC IS SOLAR DECLINATION
C          H IS SOLAR HOUR ANGLE
C          COSZ IS COSINE OF SOLAR ZENITH ANGLE
C          COSAZ IS COSINE OF SOLAR AZIMUTH
C          LXS, LYS, LZS ARE SOLAR DIRECTION COSINES
C
C
      COMMON/C1/DAY,YEAR,TIME,GLAT,GLONG,DEC,DUM(24),
     1CEDTR,CERTD,CEMTR,DUM2(17),
     2SINLAT,COSLAT,SINDEC,COSDEC,COSH,SINZ,COSZ,SINAZ,COSAZ,LXS,LYS,LZS
      REAL LXS,LYS,LZS
      H=ABS(((12.-TIME)*15.)*CEDTR)
      SINLAT=SIN(GLAT)
      COSLAT=COS(GLAT)
      SINDEC=SIN(DEC)
      COSDEC=COS(DEC)
      COSH=COS(H)
      COSZ=SINLAT*SINDEC+COSLAT*COSDEC*COSH
      SINZ=SQRT(1.-COSZ*COSZ)
      COSAZ=(SINDEC-SINLAT*COSZ)/(COSLAT*SINZ)
      SINAZ=SQRT(1.-COSAZ*COSAZ)
      LXS=SINZ*COSAZ
      LYS=SINZ*SINAZ
      LZS=COSZ
      RETURN
      END
```

```
      SUBROUTINE VMULT(X,Y,Z,N)
C.....VECTOR MULTIPLICATION
      DIMENSION X(17),Y(17,17),Z(17)
      DO 10 I=1,N
      Z(I)=0.
      DO 10 J=1,N
   10 Z(I)=Z(I)+X(J)*Y(I,J)
      RETURN
      END
```

```
      SUBROUTINE VADD(X,Y,Z,N)
      DIMENSION X(17),Y(17),Z(17)
      DO 10 I=1,N
   10 Z(I)=X(I)+Y(I)
      RETURN
      END
```

27

```
      FUNCTION GAUSS(X,S)
C.....GENERATE RANDOM SAMPLES FROM THE UNIVARIATE NORMAL DISTRIBUTION.
      X1=RANF(0.)
      X2=RANF(0.)
      C1=SIN(6.283185*X1)*SQRT(-2.*ALOG(X2))
      GAUSS=C1*S+X
      RETURN
      END
```

28

```
      SUBROUTINE UTIL(A,B)
C.....SET VECTOR B = VECTOR A
      COMMON/C1/DUM(7),NLAM
      DIMENSION A(17),B(17)
      DO 1 I=1,NLAM
    1 B(I)=A(I)
      RETURN
      END
```

2. COEFF

Program Name: COEFF

Narrative:

This program calculates the alpha and beta coefficients of a linear correction algorithm for sun angle. The form of Y = Ax + B results, where x is the measured response and Y is the spatially or temporally extended response.

Control Card Input:

<u>Card 1</u>

Column 1-5	(I5)	Number of wavelengths
Column 6-10	(I5)	Number of solar zenith angles
Column 11-80	(7A10)	Title for computation

<u>Card 2, 3, 4, etc.</u>

Column 1-10	(F10.3)	(LP)	Path radiance for sun angle THZ
Column 11-20	(F10.3)	(L)	Target irradiance for sun angle THZ
Column 21-30	(F10.3)	(RFL)	Canopy reflectance at sun angle THZ
Column 31-40	(F10.3)	(WAVEL)	Wavelength band for reflectance measurement
Column 41-50	(F10.3)	(THZ)	Solar zenith angle

All possible non-repetitive pairwise combinations of sun angles for each wavelength are computed.

C.2

```
      PROGRAM COEFF(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      REAL LP1,LP2,L1,L2
      REAL L(15),LP(15),WAVEL(15),THZ(15)
      DIMENSION RFL(15)
      DIMENSION TITLE(7)
C----THIS PROGRAM CALCULATES THE ALPHA AND BETA COEFFICIENTS
C    OF A LINEAR CORRECTION ALGORITHM FOR SUN ANGLE..
C         Y=AX+B
C    .WHERE X IS THE MEASURED RESPONSE AND Y IS THE SPATIALLY OR
C    TEMPORALLY EXTENDED RESPONSE.
C
C... INPUT
C      LP1 AND LP2
C      L1 AND L2
C... OUTPUT
C      ALPA COEFFICIENT
C      BETA COEFFICIENT
C
C        LP1 AND LP2 ARE THE RESPECTIVE PATH IRRADIANCES FOR
C          SUN ANGLE 1 AND 2.
C        L1 AND L2 ARE THE RESPECTIVE TOTAL  IRRADIANCES FOR
C          SUN ANGLE 1 AND 2.
C       THE ALPHA COEFFICIENT IS THE MULTIPLICATIVE CORRECTION.
C       THE BETA  COEFFICIENT IS THE ADDITIVE CORRECTION.
C
C
      WRITE(6,600)
  600 FORMAT(*1*)
    1 READ(5,602) NL,NANG,(TITLE(I),I=1,7)
  602 FORMAT(2I5,7A10)
      IF(EOF(5)) 5,10
   10 CONTINUE
      WRITE(6,603) NL,NANG,(TITLE(I),I=1,7)
  603 FORMAT(1H0,50X,2I5,7A10)
      DO 1000 I=1,NL
C
      DO 100 J=1,NANG
      READ(5,501) LP(J),L(J),RFL(J),WAVEL(J),THZ(J)
  501 FORMAT(5F10.3)
  100 CONTINUE
C
      DO 200 II=1,NANG
      JJJ=II+1
      DO 200 JJ=JJJ,NANG
      IF(JJ.GT.NANG) GO TO 200
      LP1=LP(II)
      LP2=LP(JJ)
      L1=L(II)
      L2=L(JJ)
      RFL1=RFL(II)
      RFL2=RFL(JJ)
      WAVEL1=WAVEL(II)
      WAVEL2=WAVEL(JJ)
      THZ1=THZ(II)
      THZ2=THZ(JJ)
C
      WRITE(6,601) LP1,L1,RFL1,WAVEL1,THZ1
  601 FORMAT(1X,*PATH IRRADIANCE*,F7.3,2X,*,TOTAL  IRRADIANCE*,F7.3,2X,*
     1FOR THETA 1...REFLECTANCE,WAVELENGTH,THETA =*,3F7.3)
```

ORIGINAL PAGE IS
OF POOR QUALITY

```
          WRITE(6,605) LP2,L2,RFL2,WAVEL2,THZ2
      605 FORMAT(1X,*PATH IRRADIANCE*,F7.3,2X,*,TARGET IRRADIANCE*,F7.3,2X,*
         1FOR THETA 2...REFLECTANCE,WAVELENGTH,THETA =*,3F7.3)
    C
    C
          ALPHA=(L2-LP2)/(L1-LR1)
          BETA=LP2-(LP1*ALPHA)
    C
    C
          WRITE(6,610) ALPHA,BETA
      610 FORMAT(1X,*ALPHA COEFFICIENT FOR 1 TO 2 =*,F7.4,10X,*BETA COEFFICI
         1ENT FOR 1 TO 2 =*,F7.4,////)
    200   CONTINUE
    1000  CONTINUE
    C
          GO TO 1
        5 CONTINUE
          STOP
          END
```

3.0 DATAUSE

Program Name: DATAUSE

Subroutines Required: PLOT1
IDIOT

Narrative:

This program is designed to reduce radiometric data obtained using the CSU J-16 spectroradiometer or other similar instruments. The program calculates reflectance from ratios of sample reading and reference panel readings. The program currently contains the option to plot reflectance versus wavelength for a given time period. The program is designed so that other options of data manipulation can easily be added in the form of another subroutine. The desired types of data manipulation can be selected and input at the start of the data section.

Control Card Input:

Card 1

Column 1-3	(I3)	(N1)	Number of PLOT types
Column 4-33	(10I3)	(N2)	Numbers to select each data manipulation option in a specific order, i.e., (#1=plot of reflectance versus wavelength "PLOT1") position 1 cols. 4-6 will be first in sequence and so on. Up to 10 data manipulation subroutines can be created and inserted in the program. At present only PLOT1 is included.

Card 2

Columns 1-30	(10I3)	(M1-M10)	The number of times each data manipulation option will be repeated.

Card 3 - until termination of data

Column 1-6	(I6)	(IDATE)	Date in 6 integers
Column 7-11	(I5)	(ITIME)	Time in 4 integers right justified
Column 13-22	(A10)	(ITAR)	Target type
Column 23-25	(I3)	(IANGL)	View angle; 2 integers right justified
Column 26-30	(I5)	(IWAVE)	Wavelength; 4 integers right justified
Column 31-37	(E7.0)	(DIRRD)	Direct radiation measure
Column 38-44	(E7.0)	(DIFRD)	Diffuse radiation measure
Column 45-51	(E7.0)	(SMPRD)	Target (sample) radiation measure
Column 66-79	(A14)	(ICOMA and ICOMB)	Extra comments

Termination of data in this format is indicated by inserting 999999 in columns 1-6.

<u>Cards following 999999 card</u> (if option PLOT1 is selected)

<u>Columns 1-40</u>	(4A10)	(LTIT)	Title of graph 1 card for each graph desired under this option

```
      PROGRAM DATAUSE (INPUT,OUTPUT,FILMPL,TAPE5=INPUT,TAPE6=OUTPUT)
C     IDATE=DATE OF OBS.,ITIME=TIME OF OBS.,ITAR=TARGET,IANGL=VIEW ANGLE FROM
C   VERTICAL,IWAVE=WAVELENGTH,DIRRD=DIRECT RD.
C     DIFRD=DIFFUSE RD.,SMPRD=SAMPLE RD.,ICOM=COMMENTS,RFLCT=REFLECTANCE
C     NSUM=TOTAL OBS.,NSET=NUMBER OF DATA SETS,INSET=NUMBER OBS. PER SET
C...ITST=TEST FOR END OF DATA SET,LTIT=TITLE FOR PLOT,LABX=LABLE X AXIS
C...LABY=LABLE Y AXIS
      DIMENSION IDATE(500),ITIME(500),ITAR(500),IANGL(500),IWAVE(500),DI
     1RRD(500),DIFRD(500),RFLCT(500),ICOMA(500),ICOMB(500),ITST(500),X(2
     10),Y(20),N2(10),LTIT(4),LABX(4),LABY(4),SMPRD(500)
      NSET=0
      ICHR=1H*
      NSUM=0
C     PRINT HEADINGS FOR DATA
      WRITE(6,100)
  100 FORMAT(*  DATE  TIME   TARGET  VIEW WL DIRECT DIFFUSE SAMPLE REFLE
     1CTANCE   COMMENTS*,/)
C...READ IN THE NUMBER OF PLOT TYPES DESIRED,(N1)
C...READ IN NUMBERS TO SELECT EACH PLOT TYPE IN THE DESIRED ORDER (N2)
C...1=PLOT1=PLOTS REFLECT. VS WAVELENGTH FOR EACH DATA SET SELECTED
      READ (5,200) N1,(N2(I),I=1,N1)
  200 FORMAT(11I3)
C...READ IN THE NUMBER OF TIMES A PLOT TYPE IS TO BE USED (M)
      READ (5,510) M1,M2,M3,M4,M5,M6,M7,M8,M9,M10
  510 FORMAT(10I3)
C     READ IN DATA,CALCULATE REFLECTANCE,WRITE OUT ALL DATA
      DO 1000 I=1,500
      READ (5,300)IDATE(I),ITIME(I),ITAR(I),IANGL(I),IWAVE(I),DIRRD(I),D
     1IFRD(I),SMPRD(I),ICOMA(I),ICOMB(I),ITST(I)
  300 FORMAT(I6,I5,1X,A10,I3,I5,3E7.0,14X,A10,A4,I1)
      IF (IDATE(I).EQ.999999) GO TO 1001
      NSUM=NSUM+1
      RFLCT(I)=SMPRD(I)/DIRRD(I)
      WRITE(6,400)IDATE(I),ITIME(I),ITAR(I),IANGL(I),IWAVE(I),DIRRD(I),D
     1IFRD(I),SMPRD(I),RFLCT(I),ICOMA(I),ICOMB(I)
  400 FORMAT(* *,I6,I5,1X,A10,I3,I5,3F7.0,F7.4,7X,A10,A4)
      IF (ITST(I).EQ.2) GO TO 1002
      IF (ITST(I).NE.1) GO TO 1000
```

```
      NSET=NSET+1
C...PROVIDE SPACE BETWEEN SETS IN PRINT OUT
      WRITE(6,410)
  410 FORMAT(*0*)
      GO TO 1000
 1002 WRITE(6,420)
  420 FORMAT(*1*)
      NSET=NSET+1
 1000 CONTINUE
 1001 CONTINUE
C     CACULATE NUMBER OFS. PER SET
      INSET=NSUM/NSET
C     PRINT OUT NSUM,NSET,INSET
      WRITE(6,500)NSUM,NSET,INSET
  500 FORMAT(*0TOTAL OBS.=*,I3,3X,*NUMBER OF DATA SETS=*,I3,3X,*NUMBER O
     1F OBS. PER SET=*,I3)
      STOP
      END
```

4.0 PLANTS

Program Name: PLANTS

Subroutines Required: IMAGE
PLOT
STATS

Functions Required: GAUSS

Narrative:

Program PLANTS is designed to generate an abstract plant canopy defined by a group of straight lines in three dimensional space. This configuration is represented by the projection of each plant element onto XZ and YZ planes. The elements in the scene can be controlled (IFIG1=1) in which the user supplies the X-Y coordinates of the plants position on the ground (XGRD,YGRD and ZGRD, where ZGRD=0.), the length of the plant (DIST), the inclination angle (THETA), and the azimuth angle (PHI). A second option (IFIG1=2) allows the user to designate plant position, as before, however, the inclination angle, plant length and azimuth angle are randomly determined. The inclination angle is determined from a normal distribution with TMEAN and TSTD. The plant length is similarly calculated from DMEAN and DSTD. Output from either mode of operation includes a microfilm plot of the orthogonal views; a graymap printout of the same views; statistics of the elements in the scene; and a permanent file containing a 64 x 64 boolean representation of the two views.

Control Card Input:

Card 1

Column 1-10	(I10)	(N)	Number of plants in a scene
Column 11-20	(I10)	(K)	Number of scenes (cases)
Column 21-30	(I10)	(KDATE)	Date of the run
Column 31-40	(I10)	(IFLG1)	Flag for random/static modes
Column 41-50	(I10)	(IFLG2)	Flag for plant branching (unavailable at present)

<u>Cards 2</u> and Following (IFLG1) - one card for each plant

Column 1-10	(F10.3)	(THETA)	Inclination angle (deg)
Column 11-20	(F10.3)	(PHI)	Azimuth angle (deg)
Column 21-30	(F10.3)	(DIST)	Plant length (inches)
Column 31-40	(F10.3)	(XGRD)	X coordinates of ground pt.
Column 41-50	(F10.3)	(YGRD)	Y coordinates of ground pt.
Column 51-60	(F10.3)	(ZGRD)	Z coordinates of ground pt.=0

<u>Card 2</u> (IFLG2) - one card for each scene (K cards)

Column 1-10	(F10.3)	(TMEAN)	Mean of inclination angle
Column 11-20	(F10.3)	(TSTD)	Standard deviation of inclination angle
Column 21-30	(F10.3)	(DMEAN)	Mean of Azimuth angle
Column 31-40	(F10.3)	(DSTD)	Standard deviation of Azimuth angle

<u>Card 3</u> + N cards (IFLG2) - one card for each plant

Column 1-10	(F10.3)	(XGRD)	X coordinates of ground pt.
Column 11-20	(F10.3)	(YGRD)	Y coordinates of ground pt.
Column 21-30	(F10.3)	(ZGRD)	Z coordinates of ground pt. Z=0

Repeat cycle of Card 2 and Cards 3 + N cards format for each new scene that is input under <u>IFLG2</u>.

<u>Example Output</u>:

Figures 1 through 4 illustrate the current flexibility of Program Plants. Each of the following figures includes a printout of the line segments generated by the program and a print of the microfilm image of the computer-generated plants in both the XZ and YZ planes. The microfilm negative produced by the program then serves as an input to an optical diffractometer to produce the corresponding diffraction patterns. Figures 1 through 3 represent different cases of the static option (IFLG1=1) in which the coordinates of plant leaves are specified. Figure 4 is an example of the random case (IFLG1=2). In this example the zenith angles were sampled from a normal distribution and the azimuthal angles from a uniform distribution.

In the examples presented here a starting x, y, z ground coordinate is specified for each plant leaf. The polar angles and line segment length are then either specified or randomly selected and permit the calculation of the end coordinates of the line segment. For example, in Figure 1 the first point is located at X=45, Y=50 (Z=0). Given a zenith angle of 45° , a azimuth angle of 270° and a length of 30 units yields an end set of coordinates of X=23.79, Y=50., and Z=21.21.

CASE NUMBER 2

X	Y	Z	THETA	PHI	DIST
45.00	50.00	0.00	45.00	270.00	30.00
23.79	50.00	21.21	0.00	0.00	0.00
47.00	50.00	0.00	45.00	270.00	30.00
25.79	50.00	21.21	0.00	0.00	0.00
49.00	50.00	0.00	45.00	270.00	30.00
27.79	50.00	21.21	0.00	0.00	0.00
51.00	50.00	0.00	45.00	270.00	30.00
29.79	50.00	21.21	0.00	0.00	0.00
53.00	50.00	0.00	45.00	270.00	30.00
31.79	50.00	21.21	0.00	0.00	0.00
55.00	50.00	0.00	45.00	270.00	30.00
33.79	50.00	21.21	0.00	0.00	0.00
MEAN			45.00	270.00	30.00
STD. DEV.			0.00	0.00	0.00

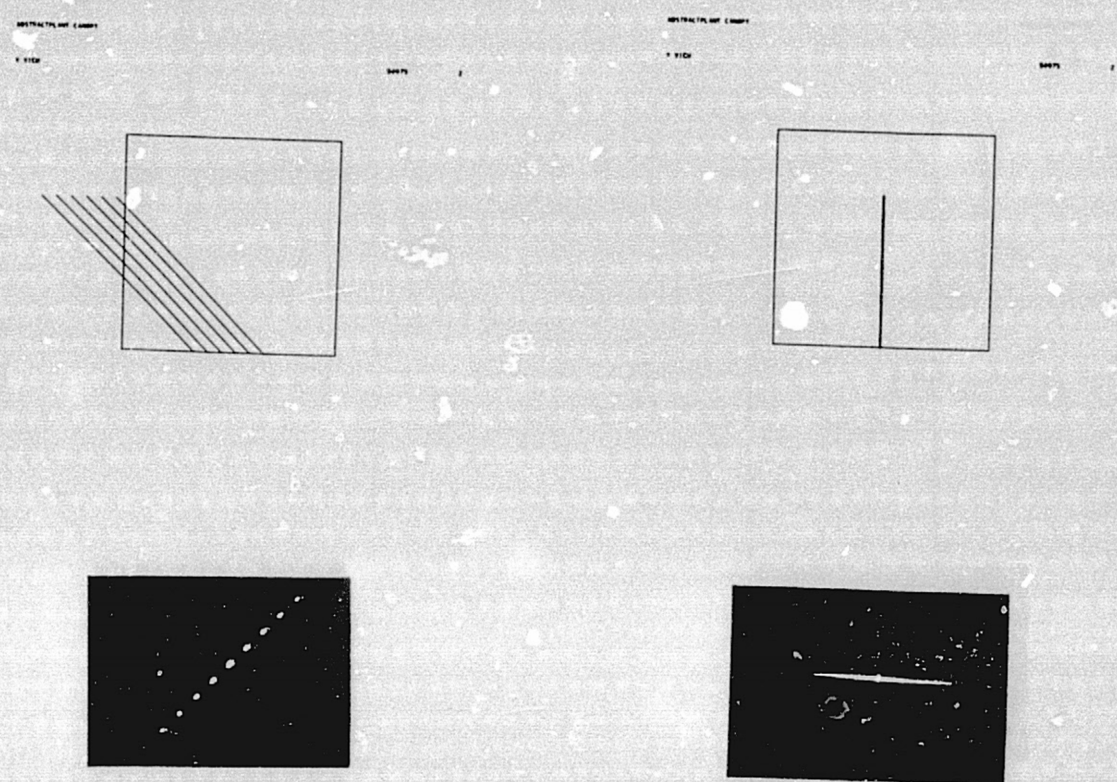

Figure 1. Output from Program Plants for Static Case 2 and optically generated Diffraction patterns. Note that within each view the border was masked; thus, only those elements within the border affect the diffraction.

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CASE NUMBER 3

X	Y	Z	THETA	PHI	DIST
45.00	45.00	0.00	60.00	315.00	30.00
26.63	63.37	15.00	0.00	0.00	0.00
47.00	47.00	0.00	60.00	315.00	30.00
28.63	65.37	15.00	0.00	0.00	0.00
49.00	49.00	0.00	60.00	315.00	30.00
30.63	67.37	15.00	0.00	0.00	0.00
51.00	51.00	0.00	60.00	315.00	30.00
32.63	69.37	15.00	0.00	0.00	0.00
53.00	53.00	0.00	60.00	315.00	30.00
34.63	71.37	15.00	0.00	0.00	0.00
55.00	55.00	0.00	60.00	315.00	30.00
36.63	73.37	15.00	0.00	0.00	0.00
MEAN			60.00	315.00	30.00
STD. DEV.			0.00	0.00	0.00

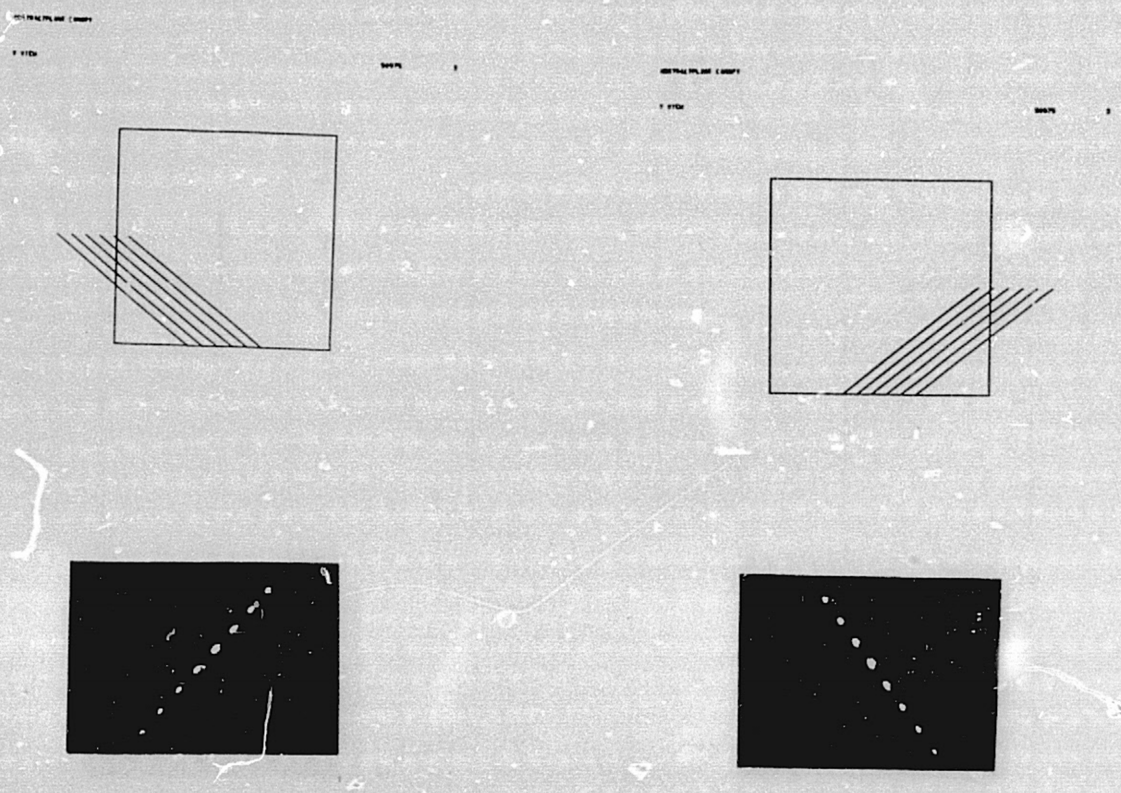


Figure 2. Output from Program Plants for Static Case 3 and diffraction patterns.

CASE NUMBER 5

	X	Y	Z	THETA	PHI	DIST
	45.00	45.00	0.00	30.00	315.00	30.00
	34.39	55.61	25.98	0.00	0.00	0.00
	47.00	47.00	0.00	30.00	315.00	30.00
	36.39	57.61	25.98	0.00	0.00	0.00
	49.00	49.00	0.00	30.00	315.00	30.00
	38.39	59.61	25.98	0.00	0.00	0.00
	51.00	51.00	0.00	30.00	315.00	30.00
	40.39	61.61	25.98	0.00	0.00	0.00
	53.00	53.00	0.00	30.00	315.00	30.00
	42.39	63.61	25.98	0.00	0.00	0.00
	55.00	55.00	0.00	30.00	315.00	30.00
	44.39	65.61	25.98	0.00	0.00	0.00
MEAN				30.00	315.00	30.00
STD. DEV.				0.00	0.00	0.00

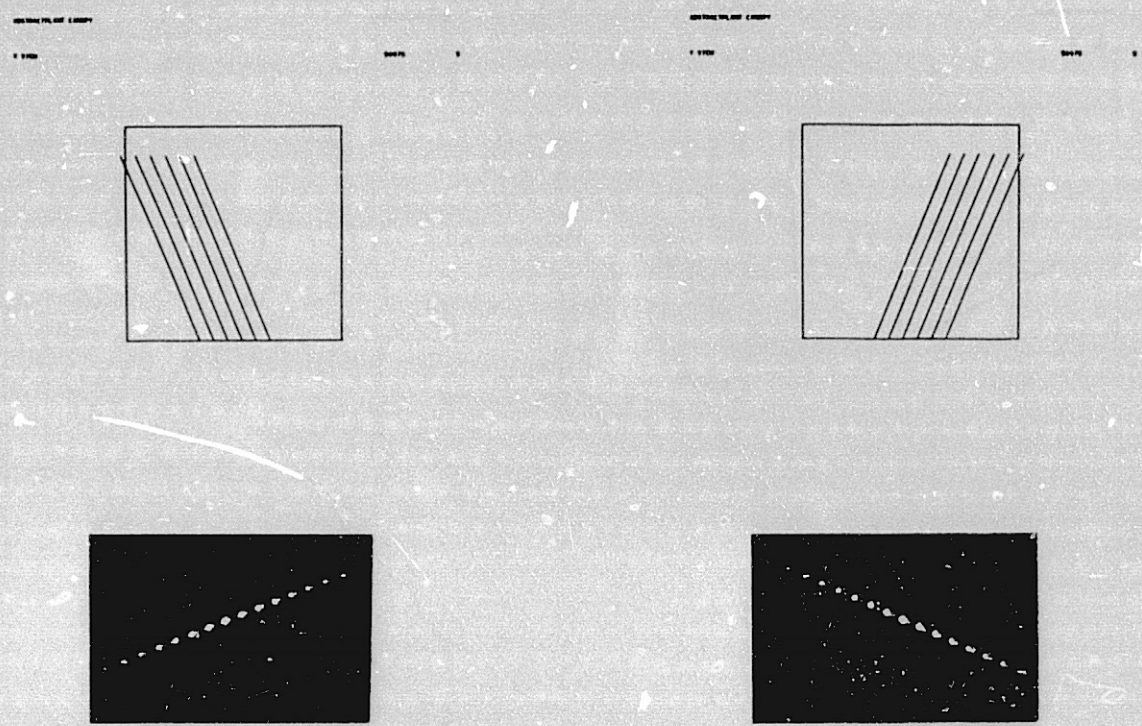
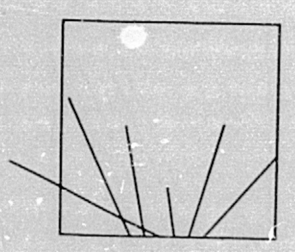
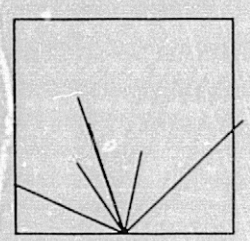


Figure 3. Output from Program Plants for Static Case 5 and corresponding Diffraction Patterns.

CASE NUMBER 2

X	Y	Z	THETA	PHI	DIST
45.00	50.00	0.00	29.68	234.90	22.05
36.07	43.72	19.16	0.00	0.00	0.00
47.00	50.00	0.00	19.69	210.11	16.37
44.23	45.23	15.42	0.00	0.00	0.00
49.00	50.00	0.00	65.51	252.93	24.22
27.93	43.53	10.04	0.00	0.00	0.00
51.00	50.00	0.00	65.37	183.77	16.68
50.00	34.87	6.95	0.00	0.00	0.00
53.00	50.00	0.00	47.00	15.81	23.20
57.62	66.33	15.82	0.00	0.00	0.00
55.00	50.00	0.00	41.97	76.38	15.51
65.08	52.44	11.53	0.00	0.00	0.00
MEAN			44.97	162.32	19.67
STD. DEV.			18.57	94.95	3.90





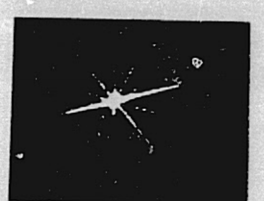


Figure 4. Output from Program Plants for Random Case 2 and corresponding optical diffraction patterns.

```
      PROGRAM PLANTS(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,FILMPL)
C.....PROGRAM PLANTS IS DESIGNED TO CALCULATE AND PLOT THE ORTHOGONAL VIEWS
C     OF AN ABSTRACT PLANT CANOPY. THE USER DEFINES THE GEOMETRIC PARAMETERS
C     OF A PLANT CANOPY IN THREE SPACE TERMS, AND THE PROGRAM DETERMINES THE
C     ORTHOGONAL PROJECTIONS AND PLOTS THE VIEWS. THE PROGRAM CAN BE OPERATED IN
C     TWO MODES...1) USER DEFINED INCLINATION ANGLES AND FIXED BASE, I) RANDOMLY
C     DETERMINED INCLINATION ANGLES IN WHICH THE USER SUPPLES THE MEAN AND
C     STANDARD DEVIATION ANDTHE COORDINATES OF THE PLANT BASES.
C.....INPUT
C          NUMBER OF PLANTS PER PLOT (N)
C          NUMBER OF PLOTS TO BE SIMULATED (K)
C          RUN IDENTIFIER (KDATE)
C          PROGRAM MODE (IFLAG1...=1, READ THETA, =2, RANDOM THETA)
C          INDICATOR FOR FIRST POINT IN A PLOT (IFLAG2... .GT. 0=FIRST POINT)
C          MEAN AND STANDARD DEVIATION OF THETA FOR A PLOT (TMEAN,TSTD....M6DE 2)
C          MEAN AND STANDARD DEVIATION OF PLANT LENGTH FOR A PLOT (DMEAN,DSTD....
C               MODE 2)
C          THREE SPACE COORDINATES OF INDIVIDUAL PLANT BASE (XGRD,YGRD,ZGRD)
C          INDIVIDUAL PLANT INCLINATION AND AZIMUTH ANGLES AND LENGTH (THETA,PHI,
C               DIST....MODE 1)
C          MEAN AND STANDARD DEVIATION FOR A PLOT (TMEAN,TSTD)
C.....OUTPUT
C          COORDINATES DEFINING LINE OF EACH PLANT IN THE SIMULATED SCENE (POINTS)
C          INCLINATION AND AZIMUTH ANGLES AND LENGTH OF EACH PLANT (ANG,AZ,PDIST)
C          STATISTICS OF PLANT CANOPY GEOMETRY (AVGT,AVGP,AVGD,STDT,STDP,STDD)
C          PRINTER PLOT OF ORTHOGONAL VIEWS (SUBROUTINE IMAGE)
C          FILM PLOT OF ORTHOGONAL VIEWS (SUBROUTINE PLOT)
C
C
C
      DIMENSION POINTS (50,3),ANG(50),AZ(50),PDIST(50)
C
C...READ AND SET PROGRAM PARAMETERS
C
      READ(5,505) N,K,KDATE,IFLG1,IFLG2
  505 FORMAT(5I10)
      WRITE(6,690) KDATE
  690 FORMAT(*1*,5X,*RUN DATE*,I8)
      MTEST=IFLG2
      L=2*N
C
C...ENTER LOOP CYCLING ON THE NUMBER OF PLOTS TO BE SIMULATED
C
      DO 200 J=1,K
C
C...TEST FOR PROGRAM MODE
C
      MTEST=MTEST + 1
      IF(IFLG1.EQ.1) GO TO 5
      IF(MTEST.GT.0) GO TO 5
C
C...READ DECRIPTIVE STATISTICS FOR RANDOMLY DETERMINING THETA AND PHI  (MODE 2)
C
      READ(5,510) TMEAN,TSTD,DMEAN,DSTD
  510 FORMAT(8F10.3)
    5 DO 10 KK=1,L
      ANG(KK)=0.
      AZ(KK)=0.
   10 PDIST(KK)=0.
```

```
      DO 100 I=1,L,2
      IF(IFLG1.EQ.1) GO TO 12
      MTEST=MTEST + 1
      IF(MTEST.GT.N) GO TO 20
C
C...READ BASE COORDINATES OF INDIVIDUAL PLANT (MODE 2)
C
      READ(5,510) XGRD,YGRD,ZGRD
C
C...DETERMINE THETA AND PHI
C
   20 RX=RANF(0.)
      IF(RX.GT.0.360) GO TO 20
      PHI=RX*1000.0
   30 THETA=GAUSS(TMEAN,TSTD)
      IF(THETA.GT.90.0.OR.THETA.LT.0.0) GO TO 30
   40 DIST=GAUSS(DMEAN,DSTD)
      IF(DIST.GT.30.0.OR.DIST.LE.5.0) GO TO 40
      GO TO 15
   12 IF(MTEST.GT.0) GO TO 15
C
C...READ THETA,PHI LENGTH,BASE COORDINATES (MODE 1)
C
      READ(5,510) THETA,PHI,DIST,XGRD,YGRD,ZGRD
C
C...DETERMINE COORDINATES OF ORTHOGONAL PROGECTIONS
C
   15 ANG(I)=THETA
      AZ(I)=PHI
      PDIST(I)=DIST
      THETA=THETA*.017453293
      PHI=PHI*.017453293
      POINTS(I,1)=XGRD
      POINTS(I,2)=YGRD
      POINTS(I,3)=ZGRD
      POINTS(I+1,1)=XGRD+(DIST*SIN(THETA)*SIN(PHI))
      POINTS(I+1,2)=YGRD+(DIST*SIN(THETA)*COS(PHI))
      POINTS(I+1,3)=ZGRD+(DIST*COS(THETA))
  100 CONTINUE
C
C...GENERATE OUTPUT
C
      WRITE(6,605) J
  605 FORMAT (////,10X,*CASE NUMBER*,I3,//,12X,*X*,09X,*Y*,09X,*Z*,7X,*T
     1HETA*,6X,*PHI*,7X,*DIST*)
      CALL STATS(ANG,N,L,AVGT,STDT)
      CALL STATS(AZ,N,L,AVGP,STDP)
      CALL STATS(PDIST,N,L,AVGD,STDD)
      DO 150 KK=1,L
      WRITE(6,615) POINTS(KK,1),POINTS(KK,2),POINTS(KK,3),ANG(KK),AZ(KK)
     1,PDIST(KK)
  615 FORMAT(5X,6F10.2)
  150 CONTINUE
      WRITE(6,620)AVGT,AVGP,AVGD
  620 FORMAT(//,5X,*MEAN *,25X,3F10.2)
      WRITE(6,625)STDT,STDP,STDD
  625 FORMAT(5X,*STD. DEV. *,20X,3F10.2)
      CALL PLOT(POINTS,J,L,N,KDATE)
      CALL IMAGE(POINTS,J,L,N,KDATE)
```

```
PROGRAM     PLANTS                         CDC 6400 FTN V3.0-P365 OPT=1  11/10/75  14.16.38.       PAGE      3

            200 CONTINUE
                STOP
                END
```

```
      SUBROUTINE IMAGE(POINTS,JCASE,LPTS,LSEG,KDATE)
      DIMENSION POINTS(50,3),PCTUR(64,64)
      DIMENSION VAR(64)
      SIZE=30. $ LSIZE=30 $ ALIGN=35. $ LALIGN=35
      NP1=64 $ NP2=64 $ LP1=64 $ LP2=64 $ NCH=1
      DEN=LP1
      DX=SIZE/DEN
      SCALE=DEN/SIZE
      LVIEW=10HXZ VIEW
      DO 100 L=1,2
      WRITE(6,670) KDATE,JCASE,LVIEW
  670 FORMAT(/////,5X,*RUN NUMBER*,I7,5X,*CASE*,I3,5X,A10,//)
      DO 10 I=1,LP1
      DO 10 J=1,NP1
   10 PCTUR(I,J)=0.
      XPT=ALIGN
      DO 50 MM=1,LP1
      DO 40 KK=1,LPTS,2
      X1=POINTS(KK,L)
      X2=POINTS(KK+1,L)
      Y1=POINTS(KK,3)
      Y2=POINTS(KK+1,3)
      JTEST=IFIX(X1+.5) $ KTEST=IFIX(X2+.5)
      IF(JTEST.EQ.KTEST) GO TO 20
      YPT=(((Y2-Y1)/(X2-X1))*(XPT-X1))+Y1
      IF(Y1.GT.Y2) Y2=Y1
      IF(YPT.GT.Y2.OR.YPT.LT.0.0) GO TO 40
      INDEXI=IFIX((DEN-(YPT*SCALE))+.5)
      PCTUR(INDEXI,MM)=100.
      GO TO 40
   20 XTEST=ABS(X1-XPT)
      DTEST=DX/2.
      IF(XTEST.LT.DTEST) GO TO 30
      GO TO 40
   30 SMALL=Y1
      IF(Y1.GT.Y2) GO TO 32
      GO TO 34
   32 SMALL=Y2 $ Y2=Y1
   34 IBOT=IFIX(DEN-((SMALL*SCALE)+.5))
      ITOP=IFIX(DEN-((Y2*SCALE)+.5))
      DO 35 LL=ITOP,IBOT
   35 PCTUR(LL,MM)=100.
   40 CONTINUE
      XPT=XPT+DX
```

```
   50 CONTINUE
      DO 60 I=1,LP1
      DO 15 J=1,64
      VAR(J)=PCTUR(I,J)
   15 CONTINUE
      WRITE(6,675)(PCTUR(I,K),K=1,LP1)
   60 CONTINUE
  675 FORMAT (1X,64F2.0)
      LVIEW=10HYZ VIEW
  100 CONTINUE
      RETURN
      END
```

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```
SUBROUTINE  PLOT                                CDC 6400 FTN V3.0-P365 OPT=1  11/10/75  14.16.38.      PAGE     1

      SUBROUTINE PLOT(POINTS,J,L,N,KDATE)
      DIMENSION LTIT(3),XPL(2),YPL(2),POINTS([illegible],3)
      LTIT(3)=10HPY [illegible] S.
      LTIT(2)=10HPLANT CANO
      LTIT(1)=10H$UABSTRACT
      DO 100 II=1,2
      CALL FRAME
      CALL SET(0.0,1.0,0.0,1.0,15.0,85.0,0.0,70.0,1)
      CALL SETLINE (1)
      CALL FRSTPT(20.0,45.0)
      CALL STRING (LTIT)
      IF (II.GT.1) GO TO 20
      LVIEW=10H$UX VIEWS.
      GO TO 30
   20 LVIEW=10H$UY VIEWS.
   30 CALL FRSTPT(20.0,40.0)
      CALL STRING(LVIEW)
      CALL FRSTPT(70.0,40.0)
      CALL NUMBR(KDATE,2HI7)
      CALL FRSTPT(80.0,40.0)
      CALL NUMBR(J,2HI2)
      CALL LINE(35.,0.,35.,30.)
      CALL LINE(35.,30.,65.,30.)
      CALL LINE(65.,30.,65.,0.)
      CALL LINE(65.,0.,35.,0.)
      DO 100 KK=1,L,2
      XPL(1)=POINTS(KK,II)
      YPL(1)=POINTS(KK,3)
      XPL(2)=POINTS(KK+1,II)
      YPL(2)=POINTS(KK+1,3)
      CALL LINE(XPL(1),YPL(1),XPL(2),YPL(2))
  100 CONTINUE
      RETURN
      END
```

```
FUNCTION    GAUSS                    CDC 6400 FTN V3.0-P365 OPT=1  11/10/75  14.16.38.      PAGE    1

            FUNCTION GAUSS(X,S)
            X1=RANF(0.)
            X2=RANF(0.)
            C1=SIN(6.283185*X1)*SQRT(-2.*ALOG(X2))
            GAUSS=C1*S+X
            RETURN
            END
```

SUBROUTINE STATS   CDC 6400 FTN V3.0-P365 OPT=1 11/10/75 14.16.38.   PAGE   1

```
      SUBROUTINF STATS(X,N,L,AVG,STD)
      DIMENSION X(50)
      TOT=0.
      SS=0.
      SAMP=N
      DO 50 KK=1,L,2
      TOT=TOT+X(KK)
      SS=SS+(X(KK)**2)
   50 CONTINUE
      AVG=TOT/SAMP
      STD=SQRT((SS-(SAMP*((TOT/SAMP)**2)))/(SAMP-1.0))
      RETURN
      END
```

5. FRDHLM

Program Name: FRDHLM

Subroutines Required: KERNAL
INVERT
DENS
COP
MATMPY
PCTAO
SETC

Narrative:

A detailed discussion of the inversion of the vector of percent vegetation cover as a function of the view angle is given in Section II.

Basically, FRDHLM inverts the following equation to solve for $f(\theta)$, the leaf slope distribution:

$$g(\theta_r) = \int_0^{\pi/2} K(\theta_r,\theta_a)\ f(\theta)\ d\theta.$$

Control Card Input:

Card 1			
Column 1-10	(A10)	(LABT)	Title of PLOT
Column 11-20	(A10)	(LABX)	Label of X axis
Column 21-30	(A10)	(LABY)	Label of Y axis
Cards 2, 3, 4			
Column 1-80; Cards 2 & 3	(8F10.0)	(G)	Probability of Gap
Column 1-30; Card 4			19 values using 10 columns for each value
Cards 5, 6, 7			
Column 1-80; Cards 5 & 6	(8F10.0)	(RSOL)	Input comparison
Column 1-30; Card 7			CURVE (can be blank)
Cards 8 and following			
Column 1-10	(F10.0)	(GAMMA)	Is a smoothing function ranging from 1-10,000; any values for gamma may be selected within this range. One value per card.

```
PROGRAM      FRDHLM                              CDC 6400 FTN V3.0-P365 OPT=1  11/11/75  09.50.37.      PAGE     1

      PROGRAM FRDHLM(INPUT,OUTPUT,FILMPL,TAPE5=INPUT,TAPE6=OUTPUT,PUNCH)
C.....PROGRAM FRDHLM IS DESIGNED TO ESTIMATE THE LEAF INCLINATION ANGLE OF
C     A LOW DENSITY PLANT CANOPY FROM THE PROBABILITY OF HIT (COVER) FROM
C     SEVERAL VIEW ANGLES. THE PROCEDURE INVOLVES SOLVING A FREDHOLM INTEGRAL
C     EQUATION OF THE FIRST KIND.
C.....INPUT
C          LABT,LABX,LABY (TITLE AND LABLES FOR FILM PLOT)
C          (VECTOR CONTAINING PROBABILITY OF HIT FOR VIEW ANGLES 0-90)
C          RSOL (COMPARISON SOLUTION- NOT USED IN CALCULATIONS)
C          GAMMA (SMOOTHING FACTOR- ANY POSITIVE NUMBER, WITH LARGER VALUES
C                EFFECTING GREATER SMOOTHING)
C          ANG (INTERNALLY DEFINED VECTOR FOR PRINTER HEADING)
C          NANG (INTERNALLY SET NUMBER OF ANGLES)
C.....OUTPUT
C          G (PROBABILITY OF VECTOR BY VIEW ANGLE)
C          GAMMA (SMOOTHING FACTOR)
C          SSE (SUM OF SQUARES ERROR TERM ASSOCIATED WITH SOLUTION)
C          F (SOLUTION VECTOR INDICATING THE LEAF ANGLE DISTRIBUTION- IF NEGATIVE
C                VALUE PERSISTS, THEY SHOULD BE SET TO ZERO AND A NEW DENSITY
C                FUNCTION FORMED OFF-LINE)
C          RSOL (READ-IN COMPARISON SOLUTION)
C
C
C
      COMMON/C2/A(19,19),B(19,19),E(19),F(19),G(19),ATN(19,19),ANG(19)
     1,AINT(19,19)
      COMMON/CPCTAO/XMI,XMA,YMA,YMI,MBX,MSX,MBY,MSY,ICHAR
      DIMENSION LABT(4),LABX(4),LABY(4),APGB(19,19),RSOL(19)
C
C...ESTABLISH HEADING AND NUMBER OF ANGLES
C
      NANG=19
      ANG(1)=0.
      DO 5 I=1,18
    5 ANG(I+1)=ANG(I)+5.
C
C...READ PROGRAM PARAMETERS
C
      READ(5,100) LABT,LABX,LABY
  100 FORMAT(8A10)
      READ(5,101) G
  101 FORMAT(8F10.0)
      READ(5,101) RSOL
      WRITE(6,200) ANG,G
C
C...ESTABLISH ASSUMED DENSITY FUNCTION FORM
C
      CALL DENS(G,19,1)
C
C...SET KERNAL VALUES, WEIGHT MATRIX,AND DETERMINE A AND B
C
      CALL KERNAL(NANG)
C
C...READ SMOOTHING FACTOR AND CYCLE UNTIL END OF FILE
C
   10 READ(5,101) GAMMA
      IF(EOF(5).NE.0.) STOP
C
C...SOLVE FREDHOLM INTEGRAL EQUATION
```

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```
C
      DO 20 I=1,NANG
      DO 20 J=1,NANG
   20 ARGB(I,J)=A(I,J)+GAMMA*B(I,J)
      CALL INVERT(ARGB,NANG)
      DO 30 I=1,NANG
      F(I)=0.
      DO 30 J=1,NANG
   30 F(I)=F(I)+ARGB(I,J)*G(J)
      DO 40 I=1,NANG
      E(I)=0.
      DO 40 J=1,NANG
   40 E(I)=E(I)-GAMMA*B(I,J)*F(J)
      FSUM=0.
      DO 49 I=1,19
   49 FSUM=FSUM+F(I)
      DO 50 I=1,19
   50 F(I)=F(I)/FSUM
C
C...GENERATE FILM PLOT
C
      XMI=0. $XMA=90. $YMI=0. $YMA=.5
      MBX=3 $MSX=3 $MBY=5  $MSY=2
      CALL PCTAP(ANG,F,19,1,1,LABT,LABX,LABY,0,0)
      ICHAR=1HE
      CALL PCTAP(ANG,RSOL,19,1,-1,LABT,LABX,LABY,1,1)
C
C...CALCULATE THE SUM OF SQUARED ERROR
C
      SSE=0.
      DO 45 I=1,19
   45 SSE=SSE+E(I)*E(I)
C
C...GENERATE PRINTER OUTPUT
C
      WRITE(6,201) GAMMA,SSE,ANG,F,E,RSOL
C
C...RECYCLE UNTIL END OF FILE
C
      GO TO 10
  200 FORMAT(*1SOLUTION TO FREDHOLM INTEGRAL OF THE FIRST KIND*,//
     13X,*ANGLE= *,19F6.1,/
     23X,*PHIT=*,19F6.3)
  201 FORMAT(////*0SOLUTION FOR GAMMA = *,F10.3,4X,*SSE = *,F10.6, /
     1*0ANGLE=*,19F6.1,/
     2*0F=  *,19F6.3,/
     3*0E=  *,19F6.3,/
     4*0RSOL*,19F6.3)
      END
```

```
      SUBROUTINE KERNAL(NANG)
C
C.....SET KERNAL VALUES. WEIGHT MATRIX, A AND B MATRICES
C
      COMMON/C1/DUM(33),CEPI02
      COMMON/C2/A(19,19),B(19,19),E(19),F(19),G(19),AIN(19,19),ANG(19)
     1,AINT(19,19)
      REAL K(19,19),W(19),H(19,19)
      CEPI02=1.570796327
C....DETERMINE KERNAL MATRIX
      DEL=90/(NANG-1)
      DEL=DEL/57.2957795
      ALPHA=-DEL
      DO 10 I=1,NANG
      ALPHA=ALPHA+DEL
      BETA=CEPI02+DEL
      DO 10 J=1,NANG
      BETA=BETA-DEL
   10 CALL COP(ALPHA,BETA,K(J,I))
C....SET WEIGHT VECTOR
      W(1)=.33333333
      DO 20 I=1,9
      W(2*I)=1.33333333
   20 W(2*I+1)=.66666666
      W(19)=.33333333
C....DETERMINE A MATRIX
      DO 30 J=1,19
      DO 30 I=1,19
   30 A(J,I)=K(J,I)*W(I)
C....DETERMINE B MATRIX
      DO 40 I=1,19
      DO 40 J=1,19
   40 AIN(I,J)=A(I,J)
      CALL INVERT(AIN,19)
      DO 45 I=1,19
      DO 45 J=1,19
   45 AINT(J,I)=AIN(I,J)
      CALL SETC(0.,H(1,1),H(19,19))
      H(1,1)=1. $H(1,2)=-2. $H(1,3)=1.
      H(2,1)=-2. $H(2,2)=5. $H(2,3)=-4. $H(2,4)=1.
      DO 50 IR=3,17
      IC1=IR-2
      H(IR,IC1)=1.
      H(IR,IC1+1)=-4.
      H(IR,IC1+2)=6.
      H(IR,IC1+3)=-4.
   50 H(IR,IC1+4)=1.
      H(18,16)=1. $H(18,17)=-4. $H(18,18)=5. $H(18,19)=-2.
      H(19,17)=1. $H(19,18)=-2. $H(19,19)=1.
      CALL MATMPY(AINT,H,B,19,19,19)
      WRITE(6,200) ((K(I,J),J=1,19),I=1,19),W,((A(MM,L),L=1,19),MM=1,19)
     1,((AIN(M,N),N=1,19),M=1,19),((H(II,JJ),JJ=1,19),II=1,23),
     2((B(KK,LL),LL=1,19),KK=1,19)
  200 FORMAT(*0K=*,19(/,3X,19F6.3),/
     1*W=*,19F6.3,/
     A *A=*,19(/,3X,19F6.3),/
     2*AIN=*,19(/,3X,19F7.2),/
     3*H=*,23(/,3X,19F7.2),/
     4 *B=*,19(/,3X,19F7.2))
      RETURN
      END
```

```
      SUBROUTINE INVERT(A,N)
C
C.....INVERT MATRIX A
C
      DIMENSION A(19,19),B(19),C(19),LZ(19)
      DO 10 J=1,N
   10 LZ(J)=J
      DO 20 I=1,N
      K=I
      Y=A(I,I)
      L=I-1
      LP = I+1
      IF(N-LP)14,11,11
   11 DO 13 J=LP,N
      W = A(I,J)
      IF(ABS(W)-ABS(Y))13,13,12
   12 K = J
      Y = W
   13 CONTINUE
   14 DO 15 J=1,N
      C(J)=A(J,K)
      A(J,K)=A(J,I)
      A(J,I)=-C(J)/Y
      A(I,J)=A(I,J)/Y
   15 B(J)=A(I,J)
      A(I,I)=1.0/Y
      J = LZ(I)
      LZ(I)=LZ(K)
      LZ(K)=J
      DO 19 K=1,N
      IF(I-K)16,19,16
   16 DO 18 J=1,N
      IF(I-J)17,18,17
   17 A(K,J)=A(K,J)-B(J)*C(K)
   18 CONTINUE
   19 CONTINUE
   20 CONTINUE
      DO 200 I=1,N
      IF(I-LZ(I))100,200,100
  100 K=I+1
      DO 500 J=K,N
      IF(I-LZ(J))500,600,500
  600 M=LZ(I)
      LZ(I)=LZ(J)
      LZ(J)=M
      DO 700 L=1,N
      C(L) = A(I,L)
      A(I,L)=A(J,L)
  700 A(J,L)=C(L)
  500 CONTINUE
  200 CONTINUE
      RETURN
      END

      SUBROUTINE MATMPY(A,B,C,M,N,L)
C
C.....MULTIPLY MATRICES A AND B
C
      DIMENSION A(M,N),B(N,L),C(M,L)
      DIMENSION A(19,19),B(19,19),C(19,19)
      DO 102 I=1,M
      DO 102 J=1,L
      S = 0.
      DO 101 K=1,N
  101 S = S+A(I,K)*B(K,J)
  102 C(I,J) = S
      RETURN
```

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```
      BLOCK DATA
      COMMON/C1/DUM(30),CEDTR,CERTD,CEMTR,CEPIO2,CE1PI,CE2PI
      DATA CEDTR,CERTD,CEMTR/.017453293,57.2957795,.00029088821/
      DATA CEPIO2,CE1PI,CE2PI/1.57079632,3.14159265,6.28318530/
      END

      SUBROUTINE DENS(G,NANG,IND)
C
C.....CALCULATE BASIC DENSITY FUNCTION FORM
C
      DIMENSION G(19)
      S = .1
      XLAI = .75
      DEL = .087266463
      TH = 0.
      DO 10 I=1,NANG
      IF(IND.EQ.1) GO TO 5
C
C...DENSITY FUNCTION 2
C
      G(I) = -ALOG(1.-G(I))*COS(TH)/XLAI
      GO TO 10
C
C...DENSITY FUNCTION 1 (SPVC)
C
5     X = S/XLAI
      G(I) = (1.-((1.-G(I))**X))*COS(TH)/S
10    TH = TH + DEL
      WRITE(6,200) G
200   FORMAT(*0  G=      *,19F6.3)
      RETURN
      END

      SUBROUTINE COP(ALPHA,BETA,OP)
C
C.....CALCULATE GEOMETRICAL PROJECTION FACTOR
C
      COMMON/C1/DUM1(33),CEPIO2
      IF(ALPHA.GT.1.57) GO TO 10
      IF (BETA.LT..02) GO TO 20
      OP = COS(ALPHA)*SIN(BETA)
      IF(ALPHA.LE.BETA)RETURN
      THETAO = ACOS(TAN(BETA)/TAN(ALPHA))
      TANTO = TAN(THETAO)
      OP = OP*(1.+(TANTO-THETAO)/CEPIO2)
      RETURN
   10 OP=COS(BETA)/CEPIO2
      RETURN
20    OP = SIN(ALPHA)/CEPIO2
      RETURN
      END

      SUBROUTINE PCTAO(DUM)
C
C.....GENERAT FILM PLOT
C
      DIMENSION DUM(54)
      RETURN
      END
```

6. PROP

Program Name: PROP

Subroutines Required: GRAPH

Narrative:

PROP accepts as input densitometer readings which wedge sample the diffraction pattern of an orthogonal view of a plant canopy. A plot of the distribution of leaf slopes contained in the original image is then generated. This program is referenced in Section II.

Control Card Input:

Card 1

Column 1-4	(I4)	(NRUN)	Number of runs
Column 5-10	(I6)	(NDATE)	Date in 6 INTEGERS
Column 11-20	(F10.5)	(DERCT)	Threshold value
Column 21-30	(F10.5)	(BADJ)	Base adjustment for aperture
Column 31-40	(F10.5)	DTEST)	Minimum divergence test value
Column 41	(I1)	(MTRAIL)	Test for end of data (other than 0 for end of data)

Cards 2 & 3

Column 1-80; Card 2 Column 1-15; Card 3	(16F5.1) (DATAE)	Densitometer values

Repeat Card 1 and Card 2 and 3 formats for each successive group of 3 data cards until all desired data has been entered. End of data is indicated by a single card with some integer value other than 0 for Column 41.

```
PROGRAM    PROP                    CDC 6400 FTN V3.0-P365 OPT=1  11/04/75  16.43.04.       PAGE    1

      PROGRAM PROP(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,PUNCH,FILMPL)
C.....PROGRAM PROP IS DESIGNED TO DEVELOP A DENSITY FUNCTION OF THE
C     ANGLES IN THE INPUT SCENE, BASED ON THE INTENSITY IN AN
C     CORRESPONDING DIFFRACTION PATTERN NEGATIVE.  THE PRINCIPAL
C     OUTPUT IS A DISTRIBUTION OF ANGLES INFERRED IN THE INPUT,
C     IN 10 DEGREE INCREMENTS FROM 0 TO 180 DEGREES.
C.....INPUT
C         THRESHOLD VALUE (PERCT)
C         BASE ADJUSTMENT FOR APERTURE (BADJ)
C         MINIMUM DIVERGENCE TEST VALUE (DTEST)
C         IDENTIFICATION (NRUN, NDATE)
C         MEASURED VALUES OF DIFFRACTION PATTERN INTENSITY (10 DEGREE INCREMENTS)
C.....OUTPUT
C         BASE VALUE
C         MAXIMUM DEVIATION IN THE DATA
C         AVERAGE DEVIATION
C         ORIGINAL DATA OF INTENSITIES OFFDIFFRACTION PATTERN
C         DEVIATIONS
C         DIFFRACTION PATTERN DENSITY FUNCTION
C         SCENE DENSITY FUNCTION
C
C
C
      DIMENSION DATAE(19),PROPORT(20),DEV(19),TEMP(19),XAXIS(19),LTIT(8)
      DIMENSION CDATA(19)
C
C...SET UP AXIS FOR GRAPHING ROUTINE
C
      DO 5 J=1,18
      XAXIS(J)=J*10.
    5 CONTINUE
      HT=10HPROPORTION
      VT=10HLEAF ANGLE
      LTIT(1)=10HDENSITY FU
      LTIT(2)=10HNCTION FOR
      LTIT(3)=10H FOURIER T
      LTIT(4)=10HECHNIQUE
      DO 6 J=5,8
    6 LTIT(J)=10H
C
C...READ PROGRAM PARAMETERS
C
      READ (5,500) PERCT,BADJ,DTEST
  500 FORMAT(3F10.5)
C
C...ENTER MAJOR LOOP
C
      DO 200 K=1,50
C
C...READ DATA
C
      READ (5,510) NRUN,NDATE
  510 FORMAT(I4,I6)
      IF(EOF(5)) 1000,7
    7 READ (5,505) (DATAE(I),I=1,19)
  505 FORMAT(16F5.1)
      IF(EOF(5)) 1000,8
C
C...DETERMINE BASE VALUE (LARGEST DATA POINT)
```

```
      PROGRAM    PROP                    CDC 6400 FTN V3.0-P365 OPT=1  11/04/75  16.43.04.      PAGE    2
C
    8 DEVTOT=0.
      BASE=DATAE(1)
      DO 10 J=2,18
      IF(BASE.LT.DATAE(J)) BASE=DATAE(J)
   10 CONTINUE
C
C...TEST FOR INCOMPATABILITY BETWEEN 0 AND 180 DEGREE READINGS. IF
C   TEST IS POSITIVE THEN THE DATA MAY BE IN ERROR.
C
      ETEST1=ABS(DATAE(1)-DATAE(19))
      ETEST2=BASE*.075
      IF(ETEST1.GE.ETEST2) GO TO 9
      GO TO 16
    9 WRITE(6,670) NRUN,NDATE
  670 FORMAT(*1*,*...............POSSIBLE ERROR IN RUN *,I4,I6)
C
C...THRESHOLD IS DETERMINED
C
   16 THRES=PERCT*BASE
C
C...DEVIATIONS ARE CALCULATED. IF 0 OR 90 OR 180 READINGS ARE INCOUNTERED
C   THE BASE VALUE IS CORRECTED FOR APETURE EFFECTS.
C
      RMAXD=0.
      DO 20 J=1,18
      IF(J.EQ.1.OR.J.EQ.10.OR.J.EQ.19) GO TO 11
      GO TO 13
   11 DEV(J)=((BASE-(BASE*BADJ))-DATAE(J))
      GO TO 15
   13 DEV(J)=BASE-DATAE(J)
   15 IF(DEV(J).LE.THRES) DEV(J)=0.
      DEVTOT=DEVTOT+DEV(J)
      IF(RMAXD.LT.DEV(J)) RMAXD=DEV(J)
   20 CONTINUE
C
C...A TEST IS MADE FOR INSUFFICIENT DIVERGENCE.
C
      IF(DEVTOT.LE.DTEST) GO TO 250
C
C...PERCENT DEVIATIONS ARE DETERMINED FOR EACH 10 DEGREE INCREMENTS.
C
      DO 30 J=1,18
      TEMP(J)=DEV(J)/DEVTOT
   30 CONTINUE
C
C...ADJUSTMENT IS MADE FOR THE 90 DEGREE ROTATION INCURRED IN THE
C   DIFFRACTION PATTERN. FOR EXAMPLE, THE PERCENT OF ANGLES IN THE 30 DEGREE
C   BAND OF THE DIFFRACTION PATTERN INDICATES THE PROPORTION OF
C   ANGLES IN THE 120 DEGREE BAND IN THE SCENE.
C
      DO 40 J=1,8
      PROPORT(J+9)=TEMP(J)
      PROPORT(J)=TEMP(J+9)
   40 CONTINUE
      PROPORT(9)=TEMP(18)
      PROPORT(18)=TEMP(9)
      PROPORT(20)=RMAXD
      AVDEV=DEVTOT/18.
```

```
      C
      C...PRINTER OUTPUT
      C
          WRITE(6,605) NRUN,NDATE,RMAXD,AVDEV,BASE
      605 FORMAT(*1*,*     RUN  *,I4,I6,5X,*MAX DEV = *,F5.1,5X,*AV DEV = *,
         1F5.1,5X,*BASE = *,F5.1,///)
          WRITE(6,610)
      610 FORMAT(*      DATA*)
          WRITE(6,650) (DATAE(I),I=1,19)
      650 FORMAT(10F8.3)
          WRITE(6,615)
      615 FORMAT(///,*     DEVIATIONS*)
          WRITE(6,650) (DEV(I),I=1,18)
          WRITE(6,630)
      630 FORMAT(///,*     DIFFRACTION PATTERN DENSITY FUNCTION VALUES*)
          WRITE(6,650) (TEMP(I),I=1,18)
          WRITE(6,620)
      620 FORMAT(///,*     DENSITY FUNCTION VALUES FOR INPUT*)
          WRITE(6,650) (PROPORT(I),I=1,18)
      C
      C...DENSITY FUNCTION VALUES FOR INPUT ANGLES 0-180 DEGREES ARE COLLAPSED
      C   TO ANGLES 0-90 DEGREES WITH INTERPRETED INCREMENTS OF 5 DEGREES.
      C
          CDATA(1)=PROPORT(1)*2.
          CDATA(19)=PROPORT(10)*2.
          INDEX=2
          DO 82 I=3,17,2
          CDATA(I)=PROPORT(INDEX)+PROPORT(20-INDEX)
       82 INDEX=INDEX+1
          INDEX=1
          DO 84 I=2,18,2
          CDATA(I)=(CDATA(INDEX)+CDATA(INDEX+2))/2.
       84 INDEX=INDEX+2
          CSUM=0.
          DO 86 I=1,19
       86 CSUM=CSUM+CDATA(I)
          DO 88 I=1,19
       88 CDATA(I)=CDATA(I)/CSUM
          WRITE(6,640)
      640 FORMAT(///,*   COLLAPSED DENSITY FUNCTION VALUES (0-90 DEG. INCL.)
         I*)
          WRITE(6,650) (CDATA(I),I=1,19)
      C
      C...PUNCHED OUTPUT
      C
          PUNCH 705,NRUN,NDATE,BASE,AVDEV
      705 FORMAT(I4,I6,2F10.5)
          PUNCH 710, (CDATA(I),I=1,19)
      710 FORMAT(8F10.4)
      C
      C...GRAPHIC OUTPUT
      C
      C   CALL MAPA(5,XAXIS,PROPORT,1,18,HL,HM,VL,VH,HT,VT,LTIT,1)
          NUMPT=18
          YMAX=0.
          DO 90 J=1,18
          IF(PROPORT(J).GT.YMAX) YMAX=PROPORT(J)
       90 CONTINUE
          MAX=(YMAX+.1)*10.
```

```
      PROGRAM      PROP                 CDC 6400 FTN V3.0-P365 OPT=1  11/04/75  16.43.04.      PAGE     4
                 YMAX=MAX
                 YMAX=YMAX/10.
                 CALL GRAPH(XAXIS,PROPORT,YMAX,NUMPT,NRUN,NDATE)
                 GO TO 200
             250 WRITE(6,625) NRUN
             625 FORMAT(*1*,*      RUN *,I8,* DOES NOT CONTAIN SIGNIFICANT DEVIATION
                1 TO DEVELOP A DENSITY FUNCTION*)
             200 CONTINUE
             300 CONTINUE
            1000 CONTINUE
                 STOP
                 END
```

```
SUBROUTINE  GRAPH                                   CDC 6400 FTN V3.0-P365 OPT=1  11/04/75  16.43.04.      PAGE     1

      SUBROUTINE GRAPH(X,Y,YMAX,NUMPT,NRUN,NDATE)
      DIMENSION X(50),Y(50)
      LTIT1=10HRUN NUMBER
      LTIT2=5HDATE
      LABX=5HANGLE
      LABY=10HPROPORTION
      CALL SET(.1,.8,.1,.8,0.,180.,0.,YMAX,1)
      CALL PWRT(5,400,LABY,10,1,1)
      CALL PWRT(430,5,LABX,5,1,0)
      CALL PWRT(382,1015,LTIT1,10,1,0)
      CALL NUMBP(NRUN,2HI3)
      CALL PWRT(395,960,LTIT2,5,1,0)
      CALL NUMBP(NDATE,2HI6)
      CALL GRDFMT(5HF10.0,5HF10.3)
      CALL PERIML(18,1,10,1)
      CALL CURVE(X,Y,NUMPT)
      CALL FRAME
      RETURN
      END
```